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12 Attorneys for Plaintiffs Bruce Technology LLC
13 and Richard Pitbladdo

14 UNITED STATES DISTRICT COURT
15 CENTRAL DISTRICT OF CALIFORNIA
16 WESTERN DIVISION

17 Bruce Technology LLC, Richard
18 Pitbladdo an individual

19 Plaintiffs,

20 v.

21 Corning Incorporated, Corning Display
22 Technologies Taiwan Co., Ltd.,
23 Corning Japan K.K., Sharp Corporation,
24 Sharp Electronics Corporation, Sharp
25 Electrónica Mexico S.A. de C.V.,
26 LG.Philips LCD Co., Ltd., LG.Philips
27 LCD America, Inc., and DOE(S) 1
28 through 10,

Defendants.

CASE NO. CV 08-00425 DDP (RCx)

FIRST AMENDED COMPLAINT FOR
PATENT INFRINGEMENT

Demand for Jury Trial

Date Filed: April 17, 2008

FILED
08 APR 17 AM 11:00
CLERK U.S. DISTRICT COURT
CENTRAL DIST. OF CALIF.
LOS ANGELES

1 **COMPLAINT**

2 Plaintiffs Richard Pitbladdo and Bruce Technology LLC ("Bruce
3 Technology"), by and through their undersigned attorneys, for its Complaint against
4 Defendants Corning Incorporated ("Corning USA"), Corning Display Technologies
5 Taiwan Co., Ltd. ("Corning Taiwan"), Corning Japan K.K. ("Corning Japan"), Sharp
6 Corporation ("Sharp Japan"), Sharp Electronics Corporation ("Sharp USA"), Sharp
7 Electrónica Mexico S.A. de C.V. ("Sharp Mexico"), LG.Philips LCD Co., Ltd.
8 ("LG.Philips Korea"), and LG.Philips LCD America, Inc. ("LG.Philips USA")
9 alleges as follows:

10
11 **JURISDICTION AND VENUE**

12 1. This action arises under the patent laws of the United States, 35 U.S.C.
13 § 101 *et seq.* This Court has original jurisdiction over the patent infringement
14 claims in this action under 28 U.S.C. §§ 1331 and 1338(a).

15 2. Venue is established in this judicial district pursuant to 28 U.S.C.
16 §§ 1391(c) and 1400(b).

17
18 **PARTIES**

19 3. Plaintiff Richard Pitbladdo is an individual residing at 6949 Bent Grass
20 Drive, Naples, Florida 34113. Mr. Pitbladdo is the named inventor in U.S. Patent
21 Nos. 6,889,526 ("the '526 patent") and 7,155,935 ("the '935 patent"), which he has
22 assigned to a family owned entity, Bruce Technology, that he founded and controls.

23 4. Plaintiff Bruce Technology is a limited liability company duly
24 registered and existing under the laws of the State of Florida with a principal place
25 of business located at 6949 Bent Grass Drive, Naples, Florida 34113 and is the
26 assignee of the '526 and '935 patents.

27 5. Defendant Corning USA operates a facility within this district at 1738
28 N. Waterman Ave., San Bernardino, CA 92404-5131 and is incorporated under the

1 laws of the state of New York with its principal place of business at One Riverfront
2 Plaza, Corning, NY 14831. Defendant Corning USA is the named assignee for U.S.
3 Patent Application Serial Nos. 10/318,268 ("the '268 application") and 10/412,112
4 ("the '112 application"). Defendant Corning USA conducts substantial business in
5 the State of California and this district; maintains a website on the Internet at
6 www.corning.com, which is accessible in this district; and causes and induces
7 infringement in this district. As alleged herein, Defendant Corning USA directly
8 infringes and has induced infringement by third parties including the Sharp and
9 LG.Phillips Defendants and its wholly owned subsidiaries in Japan, Taiwan and a
10 joint venture in Korea ("Corning Korea"), which is a majority owned subsidiary of
11 and controlled by Defendant Corning USA .

12 6. Defendant Corning Taiwan is a Taiwanese company with primary
13 locations of #33, Huan Dung Road Sec. 2, Tainan Science Based Industrial Park,
14 Tainan County 741, Taiwan, and No.1, Keyuan Road, Shi Tuen Dist., Taichung City
15 40763, Taiwan, R.O.C. Defendant Corning Taiwan manufactures the products
16 made by the methods described and claimed in Corning USA's '268 and '112
17 applications and patented by plaintiffs as alleged to be infringed herein, which are
18 sold in this judicial district. Further, Defendant Corning Taiwan is a wholly owned
19 subsidiary of Defendant Corning USA, which has induced it to infringe as alleged
20 herein.

21 7. Defendant Corning Japan is a Japanese company with a primary
22 location of 12117, Obuchi, Kakegawa-shi, Shizuoka, 437-1397, Japan. Defendant
23 Corning Japan manufactures the products made by the methods described and
24 claimed in Corning USA's '268 and '112 applications and patented by plaintiffs as
25 alleged to be infringed herein, which are sold in this judicial district. Further,
26 Defendant Corning Japan is a wholly owned subsidiary of Defendant Corning USA,
27 which has induced it to infringe as alleged herein.

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1 8. Defendant Sharp Japan is incorporated under the laws of Japan, having
2 its principal place of business in Osaka, Japan. Sharp Japan purchases LCD glass
3 made by the patented methods used by one or more of the Corning Defendants,
4 including Corning Japan which has a glass manufacturing facility on Defendant
5 Sharp's premises in Japan; manufactures the LCD products alleged to infringe
6 herein; and controls the decision of Defendant Sharp USA to infringe or license the
7 patents herein as agents of the principal parent corporation, Defendant Sharp Japan.

8 9. Defendant Sharp USA has its Western Regional Headquarters in this
9 judicial district, located at Sharp Plaza, 5901 Bolsa Avenue, Huntington Beach,
10 California 92648 and is incorporated under the laws of New York, having its
11 principal place of business at Sharp Plaza, Mahwah, NJ 07430. Defendant Sharp
12 USA offers to sell and sells infringing LCD products in this and other judicial
13 districts as alleged herein. Defendant Sharp USA is a wholly owned subsidiary of
14 Defendant Sharp Japan, which controls its operations and has induced it to sell
15 infringing LCD products as alleged herein.

16 10. Defendant Sharp Mexico is a Mexican company with a primary
17 location of Rosarito Industrial Park, Rosarito City, Baja California Mexico.
18 Defendant Sharp Mexico manufactures the LCD products alleged to infringe herein,
19 which are sold in this district. Further, Defendant Sharp Mexico is a wholly owned
20 subsidiary of Defendant Sharp Japan, which controls its operations and has induced
21 it to sell infringing LCD products as herein alleged.

22 11. Defendant LG.Philips Korea is incorporated under the laws of Korea,
23 having its principal place of business in Seoul, Korea. Defendant LG.Philips Korea
24 purchases LCD glass made by the patented methods used by Corning Korea which
25 manufactures the LCD products made by the methods alleged to be infringed herein
26 and controls the decision of Defendant LG.Philips USA to infringe or license the
27 patents herein as agents of the principal parent corporation, Defendant LG.Philips
28 Korea.

1 16. Defendant Corning USA is the named assignee for U.S. Patent
2 Application Serial Nos. 10/318,268 ("the '268 application") and 10/412,112 ("the
3 '112 application"). The '268 application claims priority from United States
4 Provisional Patent Application 60/341,199 filed December 14, 2001, and the '112
5 application claims priority from United States Provisional Patent Application
6 60/372,188 filed April 12, 2002. The Corning Defendants' use of the methods and
7 apparatuses described in the '268 and '112 applications infringes plaintiffs patents
8 asserted herein.

9 17. Defendant Corning USA has infringed the patents at issue in this case
10 through the manufacture and use of apparatuses alleged to be infringed herein for
11 the manufacture of LCD glass, which has been sold domestically and exported from
12 this country for sale, directly or indirectly through its controlled subsidiary in Korea
13 and Defendants Corning Taiwan and Corning Japan, to manufacturers of LCD
14 displays and televisions including but not limited to the Sharp and LG.Phillips
15 Defendants. These acts include, but are not limited to, the manufacture and use of
16 apparatuses patented in the United States and covered by the claims of at least the
17 two patents at issue in this case.

18 18. Defendant Corning USA both directly and through its controlled
19 subsidiary in Korea and Defendants Corning Taiwan and Corning Japan have
20 infringed the patents at issue in this case through the manufacture and sale of LCD
21 glass manufactured outside the U.S. using methods alleged to be infringed herein,
22 which has been imported into this country by the manufacturers of LCD displays
23 and televisions including but not limited to the Sharp and LG.Phillips Defendants.
24 These acts include, but are not limited to, the manufacture, use, sale, and/or
25 promotion of LCD glass which is made by methods patented in the United States
26 and covered by the claims of at least one of the patents at issue in this case, with the
27 knowledge and intent that the LCD glass would be imported into the United States
28 and this District or would be sold, resold, and/or used within the United States and

1 this District. The LCD glass includes, but is not necessarily limited to, glass sold
2 under the trade names "EAGLE 2000" and "EAGLE XG."

3 19. Defendant Corning USA is the parent corporation and United States
4 representative of its subsidiaries Corning Japan and Corning Taiwan ("Foreign
5 Corning Defendants") and Corning Korea; controls the glass manufacturing process
6 of each of its foreign subsidiaries, including instructing said subsidiaries to use the
7 patented methods as alleged herein to manufacture LCD glass; and accepts purchase
8 orders and distributes LCD glass that is made by methods patented in the United
9 States and covered by the claims of at least one of the patents identified herein, with
10 the knowledge and intent that the LCD glass would be imported into the United
11 States and into this District or would be sold, resold, and/or used within the United
12 States and this District. The LCD glass includes, but is not necessarily limited to,
13 glass sold under the trade names "EAGLE 2000" and "EAGLE XG."

14 20. Plaintiffs allege that the acts of Defendant Corning USA complained of
15 herein were done at the direction of, with the authorization of, and with the
16 cooperation, participation, assistance of and at least in part for the benefit of, the
17 Foreign Corning Defendants and Corning Korea.

18 21. Defendant Sharp Mexico, a wholly owned subsidiary of Defendant
19 Sharp Japan, has committed the acts described herein within this District. These
20 acts include, but are not limited to, the use, sale, and/or promotion of flat panel
21 displays containing LCD glass which is made by methods patented in the United
22 States and covered by the claims of at least one of Plaintiffs' patents, with the
23 knowledge and intent that the flat panel displays would be imported into the United
24 States and this District or would be sold, resold, and/or used within the United States
25 and this District. The LCD glass contained in the displays includes, but is not
26 necessarily limited to, glass sold under the trade names "EAGLE 2000" and
27 "EAGLE XG."

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1 22. Defendant Sharp USA, a wholly owned subsidiary of Defendant Sharp
2 Japan, is the United States representative of Defendant Sharp Mexico, and accepts
3 purchase orders and distributes flat panel displays containing LCD glass which is
4 made by methods patented in the United States and covered by the claims of at least
5 one of Plaintiffs' patents, with the knowledge and intent that the flat panel displays
6 would be imported into the United States and this District or would be sold, resold,
7 and/or used within the United States and this District. The LCD glass contained in
8 the displays includes, but is not necessarily limited to, glass sold under the trade
9 names "EAGLE 2000" and "EAGLE XG."

10 23. The acts of Defendant Sharp USA complained of herein were done at
11 the direction of, with the authorization of, and with the cooperation, participation,
12 assistance of and at least in part for the benefit of, Defendants Sharp Mexico and the
13 corporate parent Sharp Japan.

14 24. Defendant LG.Philips USA accepts purchase orders and distributes flat
15 panel displays containing LCD glass that are made by methods patented in the
16 United States and covered by the claims of at least one of Plaintiffs' patents, with the
17 knowledge and intent that the flat panel displays would be imported into the United
18 States and into this District or would be sold, resold, and/or used within the United
19 States and this District. The LCD glass contained in the displays includes, but is not
20 necessarily limited to, glass sold under the trade names "EAGLE 2000" and
21 "EAGLE XG" which is manufactured by products which infringe the patent at issue
22 in this suit.

23 25. The acts of Defendant LG.Philips USA complained of herein were
24 done at the direction of, with the authorization of, and with the cooperation,
25 participation, assistance of and at least in part for the benefit of, the corporate parent
26 Defendant LG.Philips Korea.

27

28

COUNT I – PATENT INFRINGEMENT (U.S. Pat. No. 6,889,526)

26. Plaintiffs realleges and incorporates by reference paragraphs 1 through 23, inclusive, as though fully set forth in this paragraph.

27. Bruce Technology is the owner and assignee of United States Patent No. 6,889,526 ("the '526 patent") entitled "Overflow Downdrawn Glass Forming Method and Apparatus," a copy of which is attached to this Complaint as Exhibit A. The '526 patent was duly and legally issued by the United States Patent and Trademark Office on May 10, 2005.

28. Defendant Corning USA has been infringing the '526 patent by making and using apparatuses claimed in the '526 patent for the manufacture of LCD glass, which has been sold domestically and exported from this country for sale, directly or indirectly through its controlled subsidiary in Korea and Defendants Corning Taiwan and Corning Japan, to manufacturers of LCD displays and televisions including but not limited to the Sharp and LG.Phillips Defendants which are later imported, offered for sale, sold or resold in the United States and this District.

29. Defendant Corning USA is not licensed or otherwise authorized by Bruce Technology to make or use the apparatuses claimed in the '526 patent.

30. Defendant Corning USA's activities render it guilty of infringing one or more claims of the '526 patent, under 35 U.S.C. § 271.

31. Defendant Corning USA's infringement of the '526 patent has been and continues to be willful since Defendant Corning USA is aware of the '526 patent and in fact attempted to patent said technology by filing a later patent application and attempting to provoke an interference with the '526 patent.

32. By reason of Defendant Corning USA's infringing activities, Bruce Technology has suffered, and will continue to suffer, substantial damages in an amount to be proven at trial.

COUNT II – PATENT INFRINGEMENT (U.S. Pat. No. 7,155,935)

33. Plaintiffs reallege and incorporate by reference paragraphs 1 through 31, inclusive, as though fully set forth in this paragraph.

34. Bruce Technology is the owner and assignee of United States Patent No. 7,155,935 ("the '935 patent") entitled "Sheet Glass Forming Apparatus," a copy of which is attached to this Complaint as Exhibit B. The '935 patent was duly and legally issued by the United States Patent and Trademark Office on January 2, 2007.

35. Defendant Corning USA has been infringing the '935 patent by making and using apparatuses claimed in the '935 patent for the manufacture of LCD glass, which has been sold domestically and exported from this country for sale, directly or indirectly through its controlled subsidiary in Korea and Defendants Corning Taiwan and Corning Japan, to manufacturers of LCD displays and televisions including but not limited to the Sharp and LG.Phillips Defendants which are later imported, offered for sale, sold or resold in the United States and this District.

36. Defendants, individually and jointly with others, have been infringing the '935 patent by making, using, offering for sale, selling and reselling, or importing into the United States and this District, LCD glass, alone and as an component of flat panel displays, which is made by methods claimed in the '935 patent.

37. Defendants have been aiding and abetting, actively inducing, and/or contributing to infringement of the '935 patent by Defendants and non-parties.

38. Defendants are not licensed or otherwise authorized by Bruce Technology to make, use, offer for sale, sell, resell, or import LCD glass, alone and as an component of flat panel displays, which is made by methods claimed in the '935 patent.

39. Defendants' activities render them guilty of infringing one or more claims of the '935 patent, under 35 U.S.C. § 271.

1 40. Defendants' infringement of the '935 patent has been and continues to
 2 be willful since Defendant Corning USA is aware of the '935 patent and in fact
 3 attempted to patent said technology by filing a later patent application and
 4 attempting to provoke an interference with the '935 patent.

5 41. By reason of Defendants' infringing activities, Bruce Technology has
 6 suffered, and will continue to suffer, substantial damages in an amount to be proven
 7 at trial.

8 9 **PRAYER FOR RELIEF**

10 Wherefore, Plaintiffs respectfully pray for judgment against Defendants
 11 as follows:

12 (a) A declaration that U.S. Patent No. 6,889,526 is valid and enforceable;

13 (b) A declaration that United States Patent No. 6,889,526 is infringed by
 14 Defendant Corning USA's acts;

15 (c) A declaration that U.S. Patent No. 7,155,935 is valid and enforceable;

16 (d) A declaration that United States Patent No. 7,155,935 is infringed by
 17 Defendants' acts;

18 (e) An award to Mr. Pitbladdo and Bruce Technology of all available and
 19 legally permissible damages caused by Defendants' infringing acts, but in no event
 20 less than a reasonable royalty and prejudgment interest thereon;

21 (f) A declaration that Defendants' infringing acts amount to willful patent
 22 infringement, and on such basis, an award of damages up to three times the amount
 23 of actual damages proven;

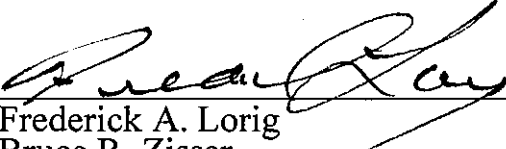
24 (g) A declaration that this case is exceptional under 35 U.S.C. § 285, and
 25 on such basis, an award of attorney fees for Plaintiffs against Defendants;

26 (h) An award to Mr. Pitbladdo and Bruce Technology of costs, pre-
 27 judgment and post-judgment interest; and
 28

1 (i) An award to Mr. Pitbladdo and Bruce Technology of such other and
2 further legal and equitable relief as this Court deems just and proper.
3

4 DATED: April 17, 2008

QUINN EMANUEL URQUHART OLIVER &
HEDGES, LLP

5
6 By  _____

7 Frederick A. Lorig
8 Bruce R. Zisser
9 Joseph M. Paunovich
Attorneys for Plaintiffs Bruce Technology
LLC and Richard Pitbladdo
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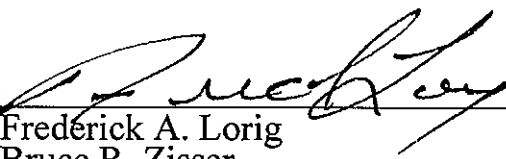
JURY DEMAND

Pursuant to Fed. R. Civ. P. 38(b), Bruce Technology demands a trial by jury on all matters and issues triable by jury.

DATED: April 17, 2008

QUINN EMANUEL URQUHART OLIVER &
HEDGES, LLP

By


Frederick A. Lorig
Bruce R. Zisser
Joseph M. Paunovich
Attorneys for Plaintiff Bruce Technology
LLC and Richard Pitbladdo



US006889526B2

(12) **United States Patent**
Pitbladdo

(10) **Patent No.:** **US 6,889,526 B2**
(45) **Date of Patent:** **May 10, 2005**

(54) **OVERFLOW DOWNDRAWN GLASS FORMING METHOD AND APPARATUS**

(76) **Inventor:** **Richard B. Pitbladdo**, 6949 Bentgrass Dr., Naples, FL (US) 34113

(*) **Notice:** Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 319 days.

(21) **Appl. No.:** **10/214,904**

(22) **Filed:** **Aug. 8, 2002**

(65) **Prior Publication Data**

US 2003/0029199 A1 Feb. 13, 2003

Related U.S. Application Data

(60) Provisional application No. 60/310,989, filed on Aug. 8, 2001, provisional application No. 60/316,676, filed on Aug. 31, 2001, provisional application No. 60/318,726, filed on Sep. 12, 2001, provisional application No. 60/318,808, filed on Sep. 13, 2001, provisional application No. 60/345,464, filed on Jan. 3, 2002, and provisional application No. 60/345,465, filed on Jan. 3, 2002.

(51) **Int. Cl.** **C03B 17/06**

(52) **U.S. Cl.** **65/53; 65/121; 65/195**

(58) **Field of Search** **65/53, 121, 195**

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,759,229 A 2/1928 Drake
1,673,907 A 6/1928 Ferngren
1,697,227 A 1/1929 Danner

(Continued)

FOREIGN PATENT DOCUMENTS

DE 1596484 7/1967
DE 1596402 12/1967
DE 1596403 12/1967

(Continued)

OTHER PUBLICATIONS

Bottger, et al.; "LCD substrate—the future process" International Glass Review, Issue 2—2000; 3 pages.

Bocko, Peter L. and Mitchell, Mark H. "AMLCD Glass Substrates—Foundation for High-Tech Displays" The GlassResearcher, vol. 12, No. 1, pp. 26–29, 2002, no month available.

Varshneya, Arun, "Fundamentals of Inorganic Glasses", Academic Press, Inc., 1994, pp. 534–540.

Snyder, R.D./Byars, E.F., "Engineering Mechanics", McGraw-Hill Book Company, 1973, pp. 349–350.

Kingery, W.D.; Bowen, H.K.; Uhlmann, D.R., "Introduction to Ceramics", John Wiley & Sons, 1976, pp. 705–767.

Primary Examiner—Sean Vincent

(74) *Attorney, Agent, or Firm*—Brown & Michaels, PC

(57) **ABSTRACT**

One embodiment of the present invention is an improved sheet glass forming apparatus. In another embodiment, a precise thermal control system redistributes the flow of molten glass at the weirs to counteract the degradation of the sheet forming apparatus which inevitably occurs during manufacturing. In yet another embodiment, the invention introduces a counteracting force to the stresses on the trough in a manner such that the thermal creep which inevitably occurs has a minimum impact on the glass flow characteristics of the forming trough. Another embodiment creates a variable external cross-section which provides hydraulic stresses that are in opposition to the surface tension and body force stresses and thus, reduces the influence of surface tension and body forces. In an alternative embodiment, the glass is preferentially cooled across its width to create forming stresses during solidification, which ensures that the glass sheet drawn is inherently flat. In an additional embodiment, the internal pressure is adjusted in each of the major components of the forming apparatus such that the pressure difference across any leakage path to the forming zone is essentially zero. Therefore, air leakage in the apparatus is minimized even though the cracks and openings exist during initial operation and develop during manufacturing.

81 Claims, 32 Drawing Sheets

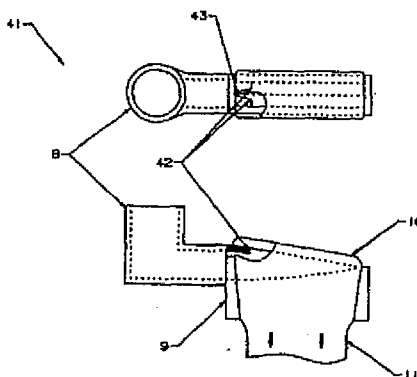


EXHIBIT A

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U.S. PATENT DOCUMENTS

1,731,260 A	10/1929	Nobbe	
1,829,639 A	10/1931	Ferngren	
1,829,641 A	10/1931	Ferngren	
1,841,579 A	1/1932	Fraser	
1,891,370 A	12/1932	Danner	
3,149,949 A	9/1964	Dockerty et al.	65/53
3,338,696 A	8/1967	Dockerty	65/145
3,433,613 A	3/1969	Dockerty	65/145
3,437,470 A	4/1969	Overman	65/195
3,451,798 A	6/1969	Simon	65/199
3,506,429 A	4/1970	Overman	65/203
3,519,411 A	7/1970	Cortright et al.	65/90
3,589,887 A	6/1971	Ward	65/195
3,607,182 A	9/1971	Leibowitz	65/53
3,682,609 A	8/1972	Dockerty	65/83
3,723,082 A	3/1973	Knowles et al.	65/84
4,214,886 A	7/1980	Shay et al.	62/121
4,416,678 A	11/1983	Boltger	65/2
5,374,595 A	12/1994	Dumbaugh, Jr. et al.	501/66
6,319,867 B1	11/2001	Chacon et al.	501/66
2001/0039814 A1	11/2001	Pitbladdo	65/193
2003/0110804 A1	6/2003	Fenn et al.	65/90
2003/0192349 A1	10/2003	Meda et al.	65/53
2004/0055338 A1 *	3/2004	Helfinstine et al.	65/374.13

FOREIGN PATENT DOCUMENTS

DE	21 58 253	11/1971
DE	31 11484 A1	2/1983
DE	33 16795	11/1983
DE	31 11484 C2	12/1983
DE	33 14540	12/1983
DE	3329843	5/1984
DE	3507852	8/1985
DE	3518137	1/1986
DE	43 36 046	10/1993
DE	43 26 143	12/1993
DE	196 44 673	4/1998
DE	198 09 878	9/1999
DE	198 40 113	3/2000
DE	19964043	7/2001
DE	100 21 013	11/2001
DE	100 28 741	12/2001
FR	1549081	12/1967
FR	1549915	1/1968
GB	982153	2/1965
JP	09110443	4/1997
JP	10291827	11/1998
JP	11-246230	9/1999
JP	2001-80922	9/1999

* cited by examiner

EXHIBIT A

U.S. Patent

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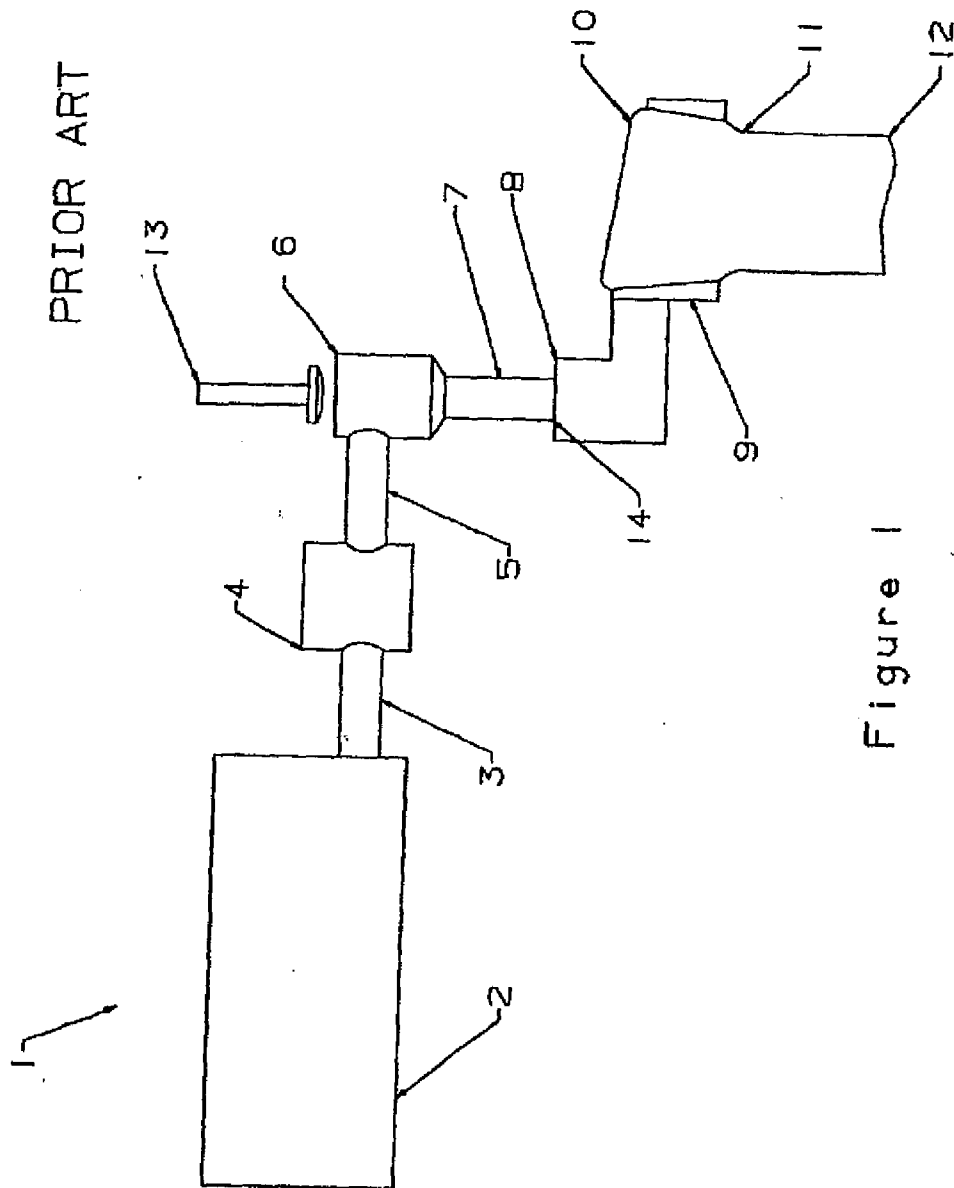
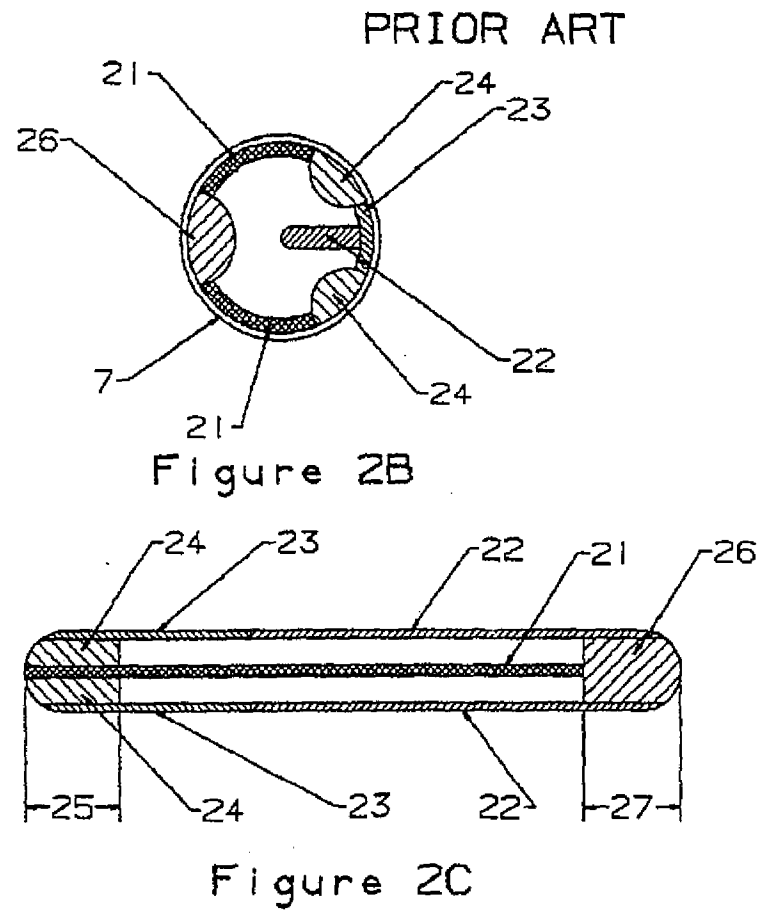
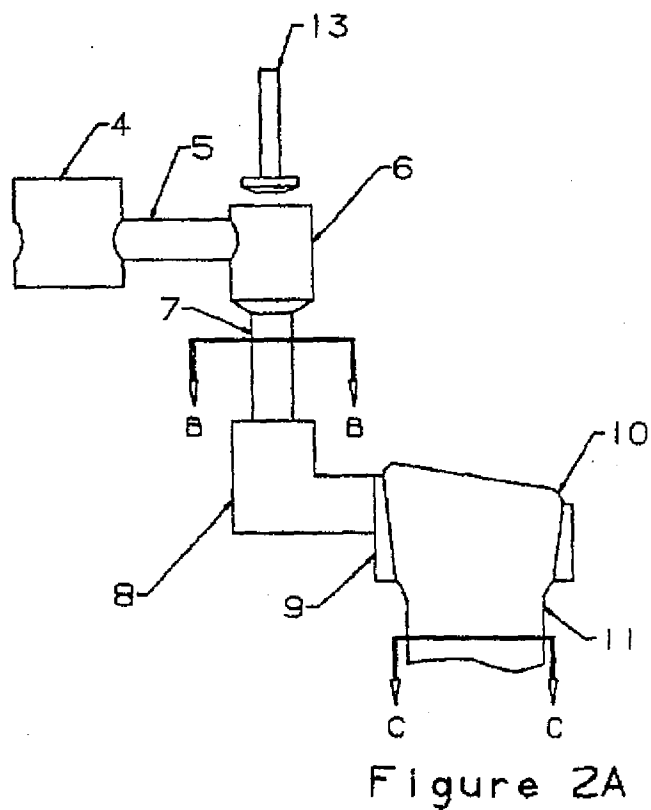


EXHIBIT A



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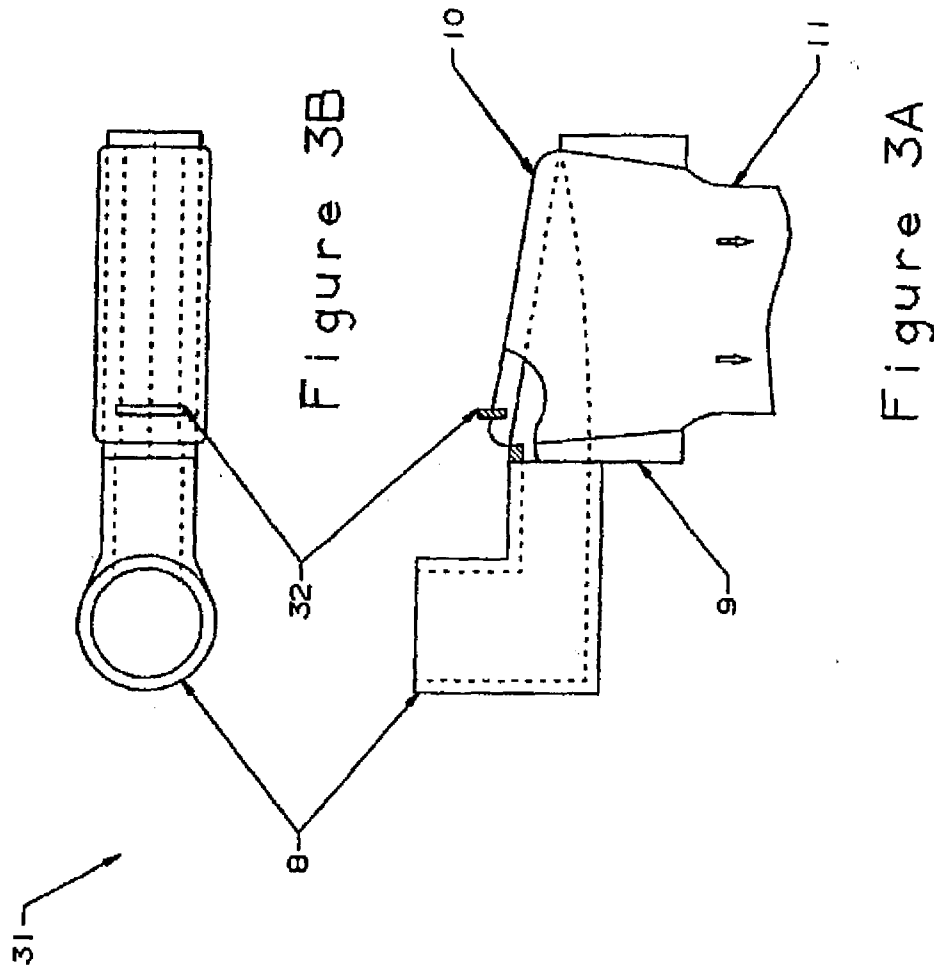
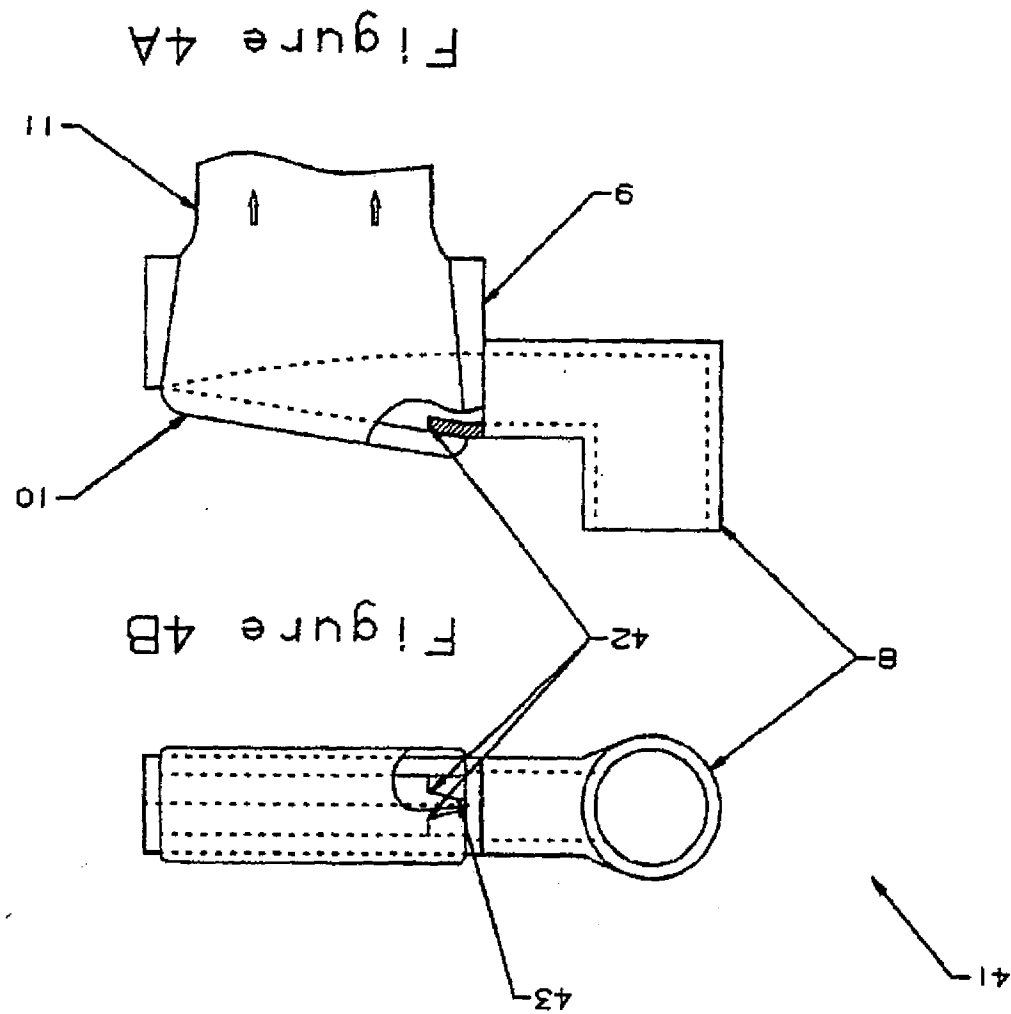


EXHIBIT A



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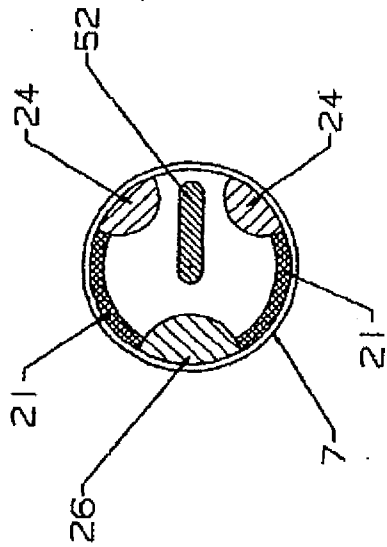


Figure 5B

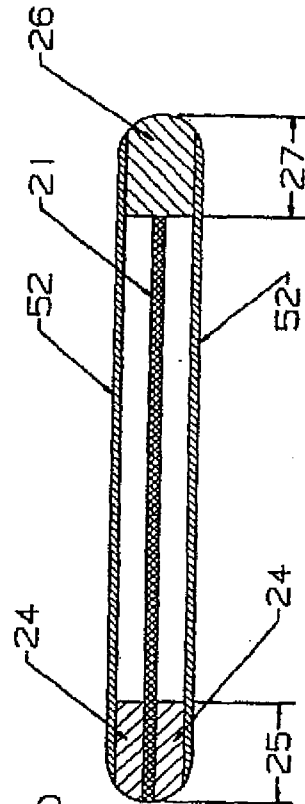


Figure 5C

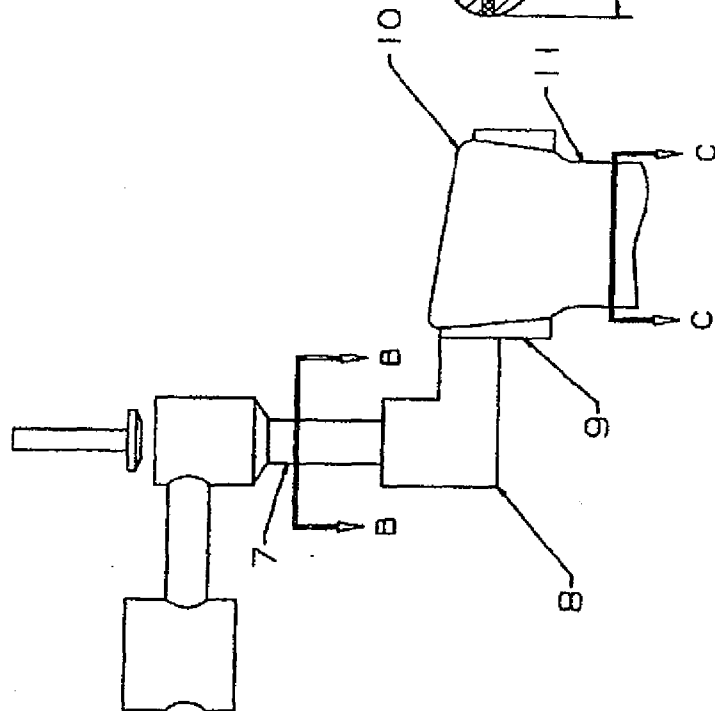


Figure 5A

EXHIBIT A

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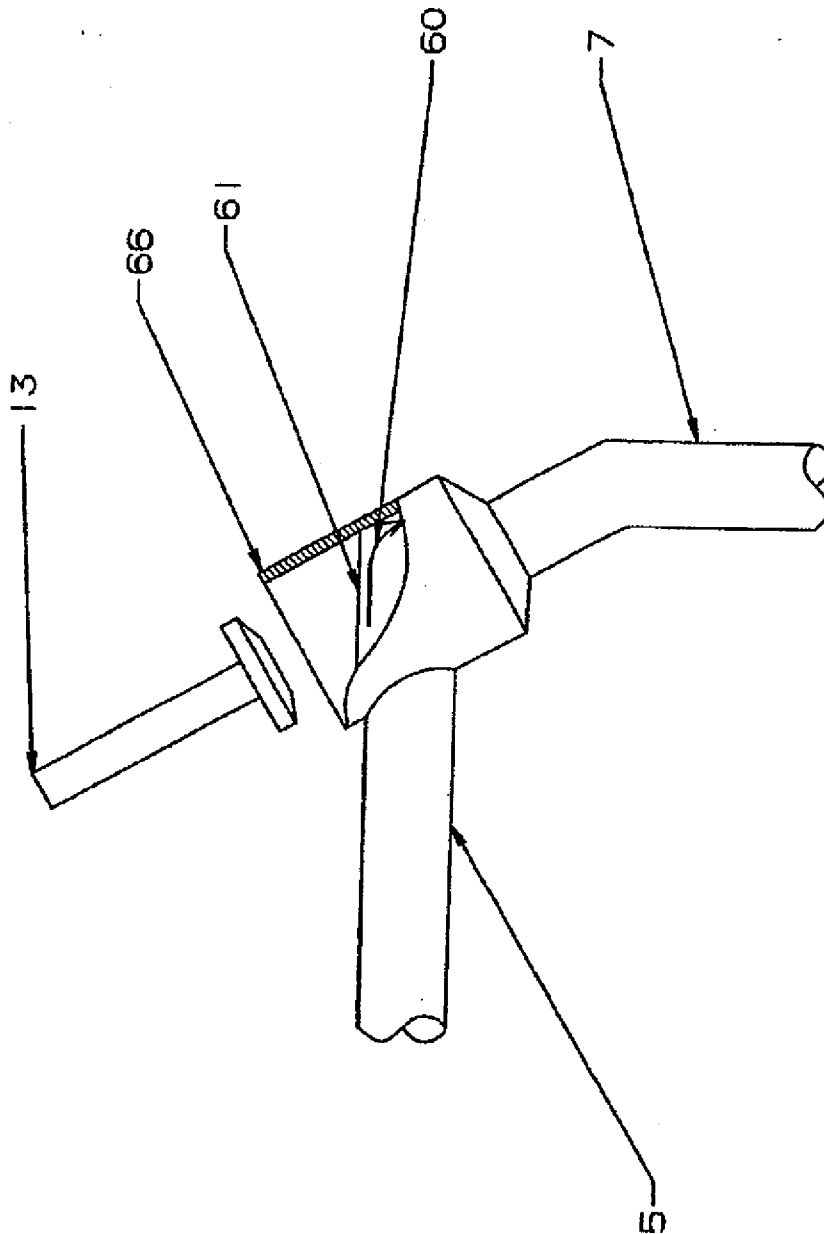


Figure 6

EXHIBIT A

U.S. Patent

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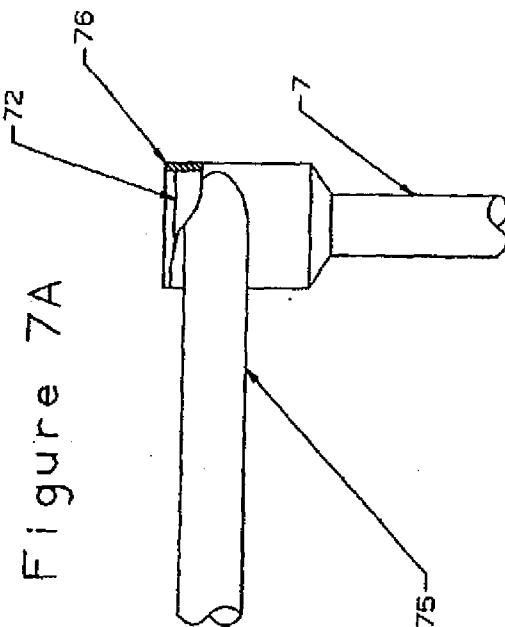
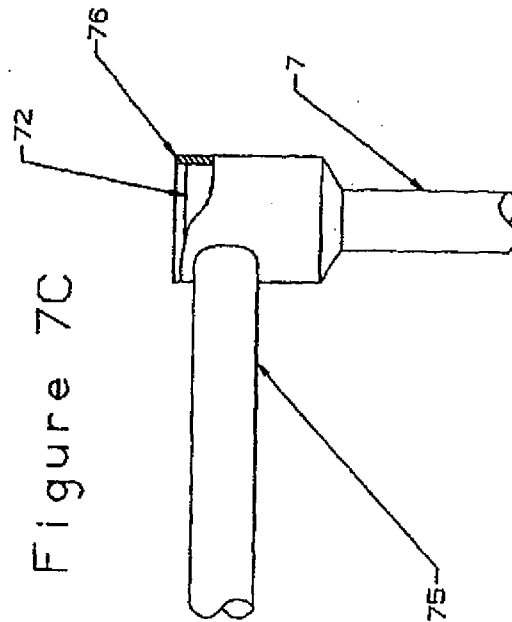
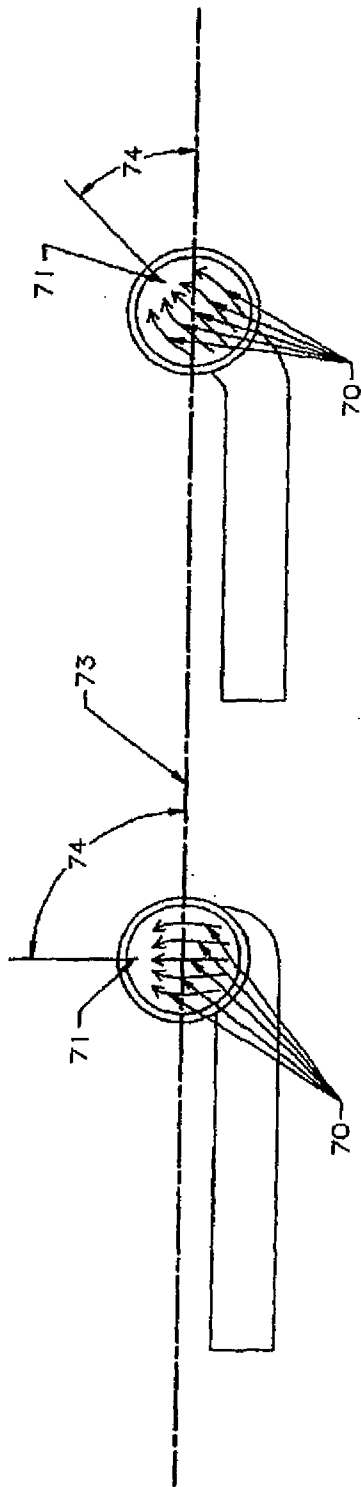


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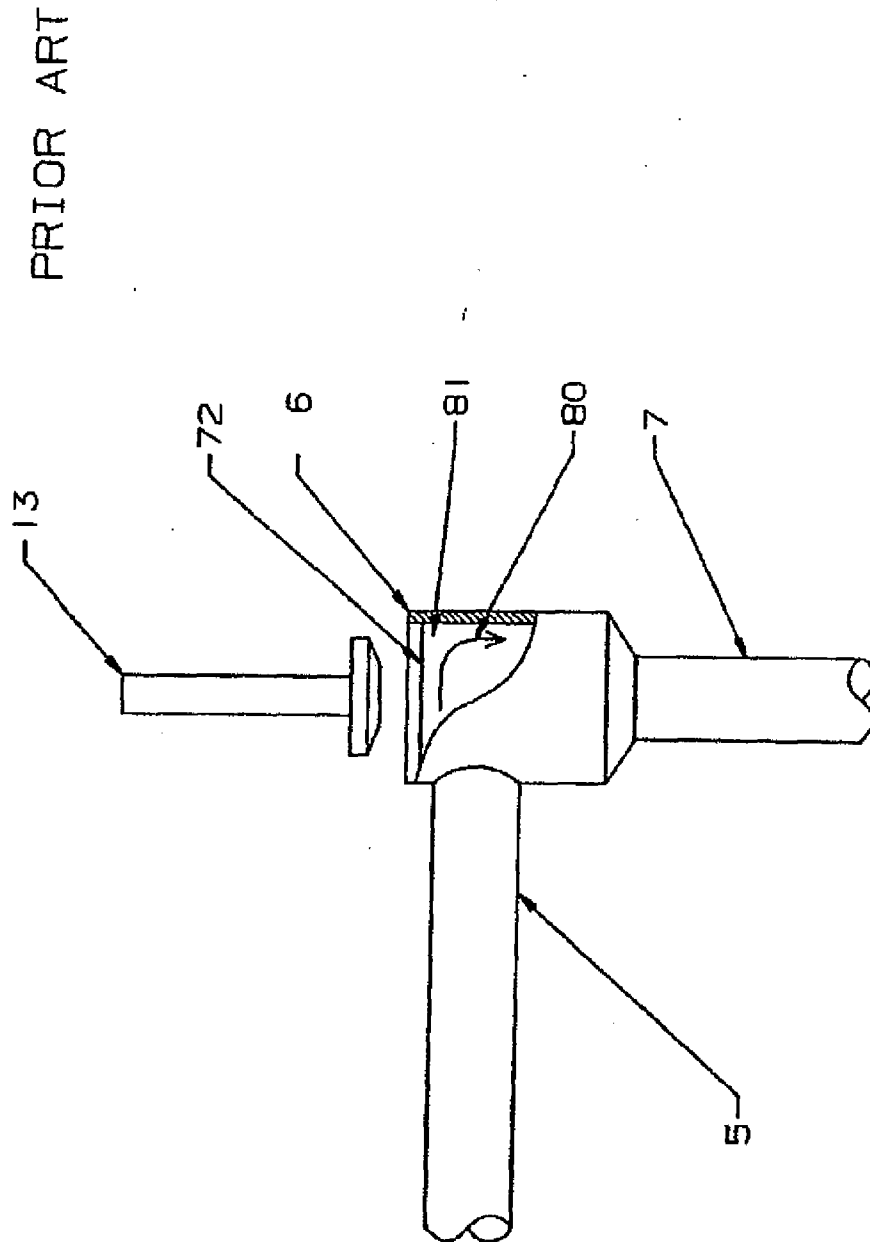


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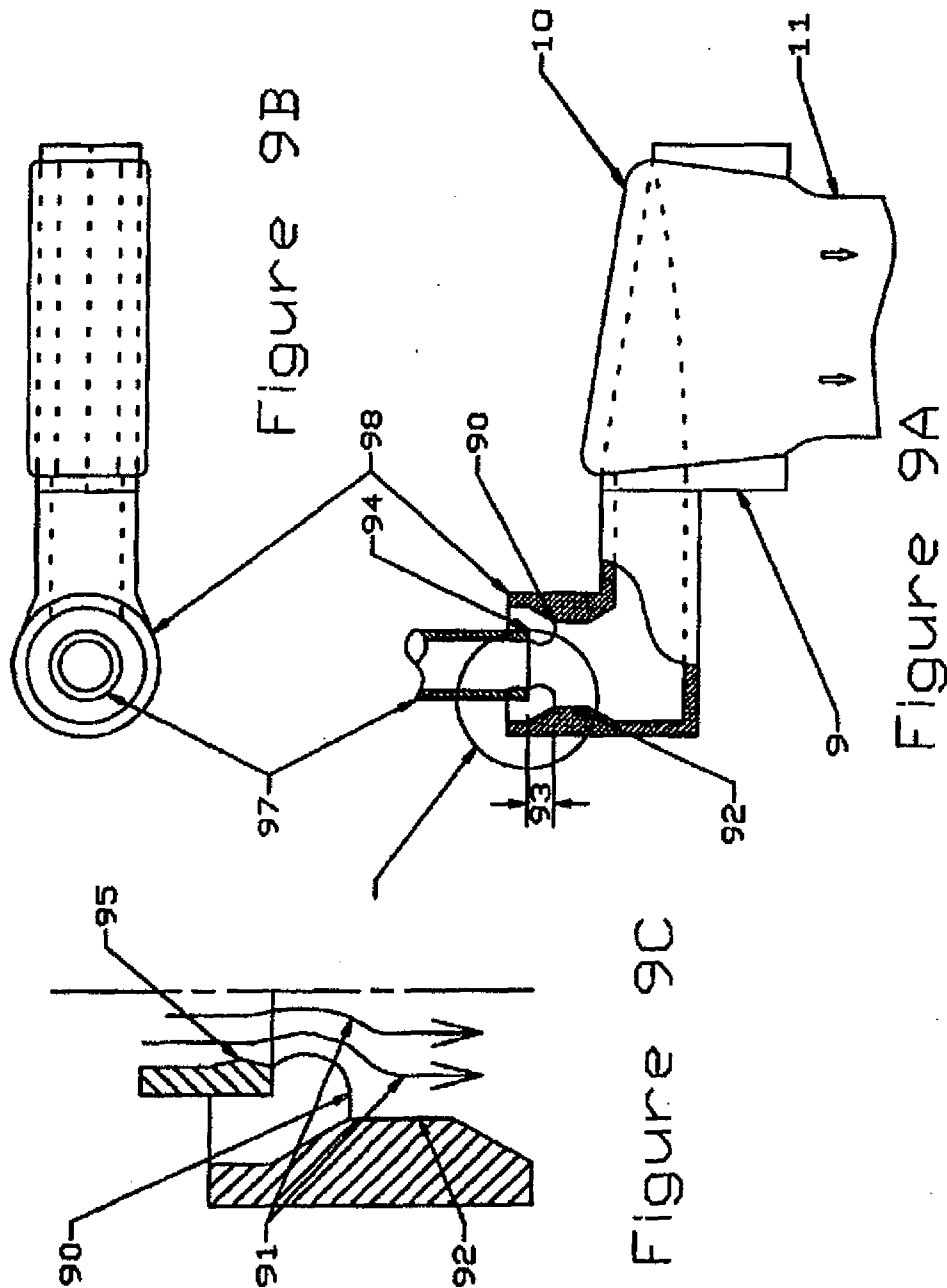


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PRIOR ART

Figure 10B

Figure 10A

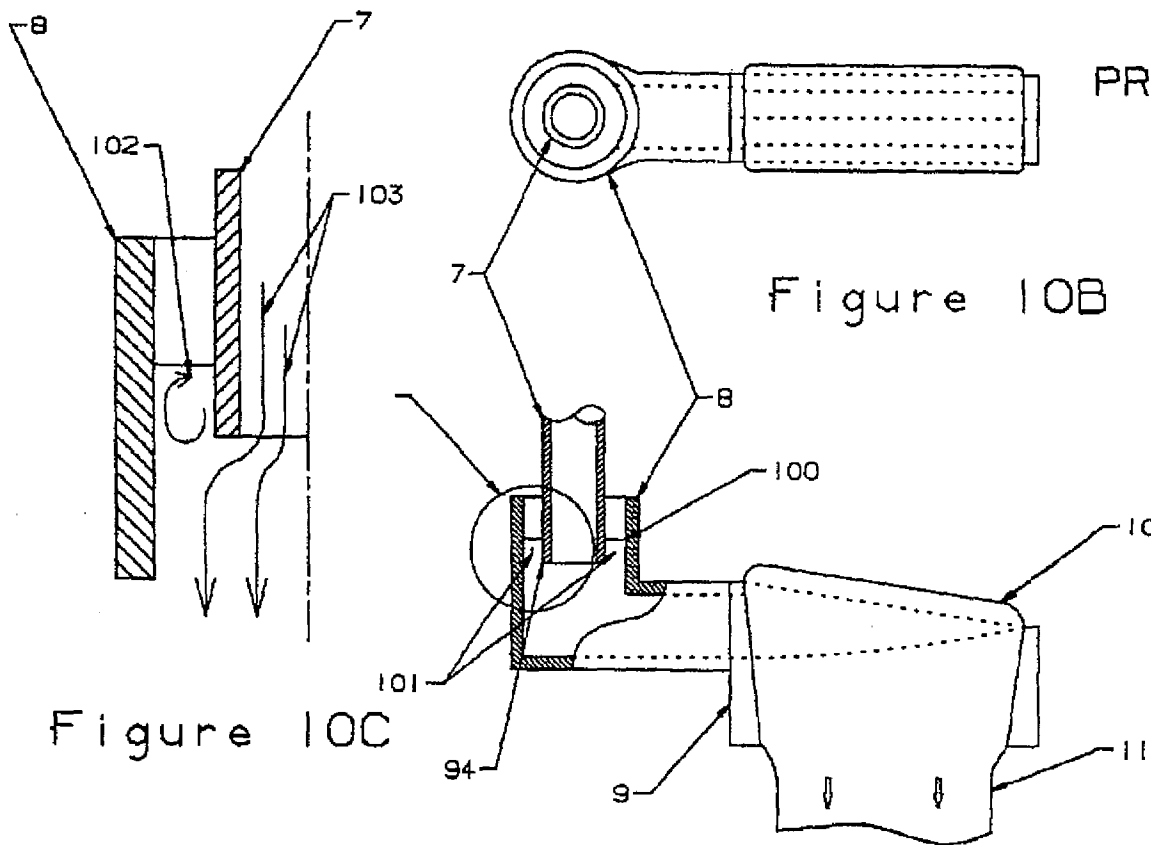


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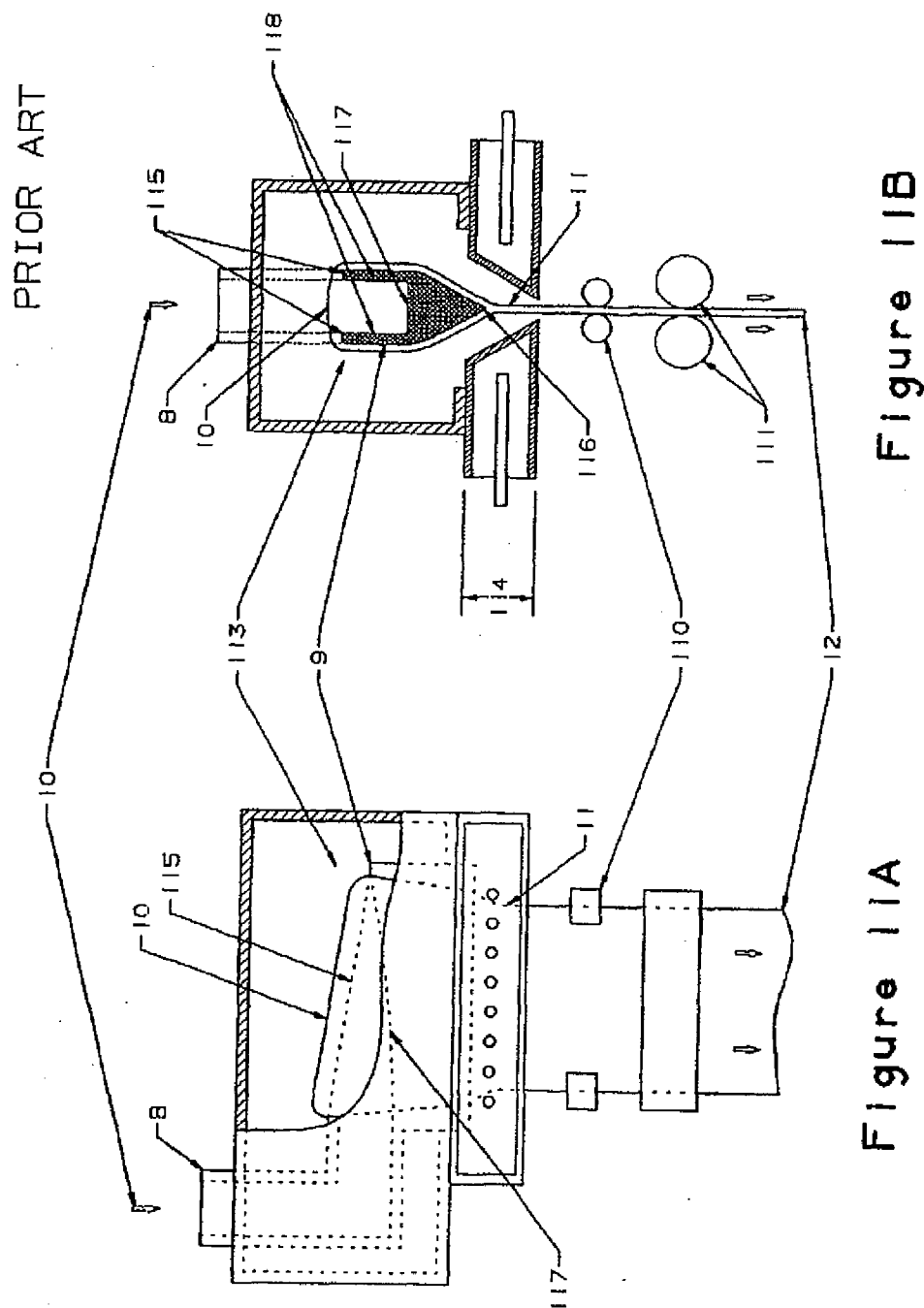


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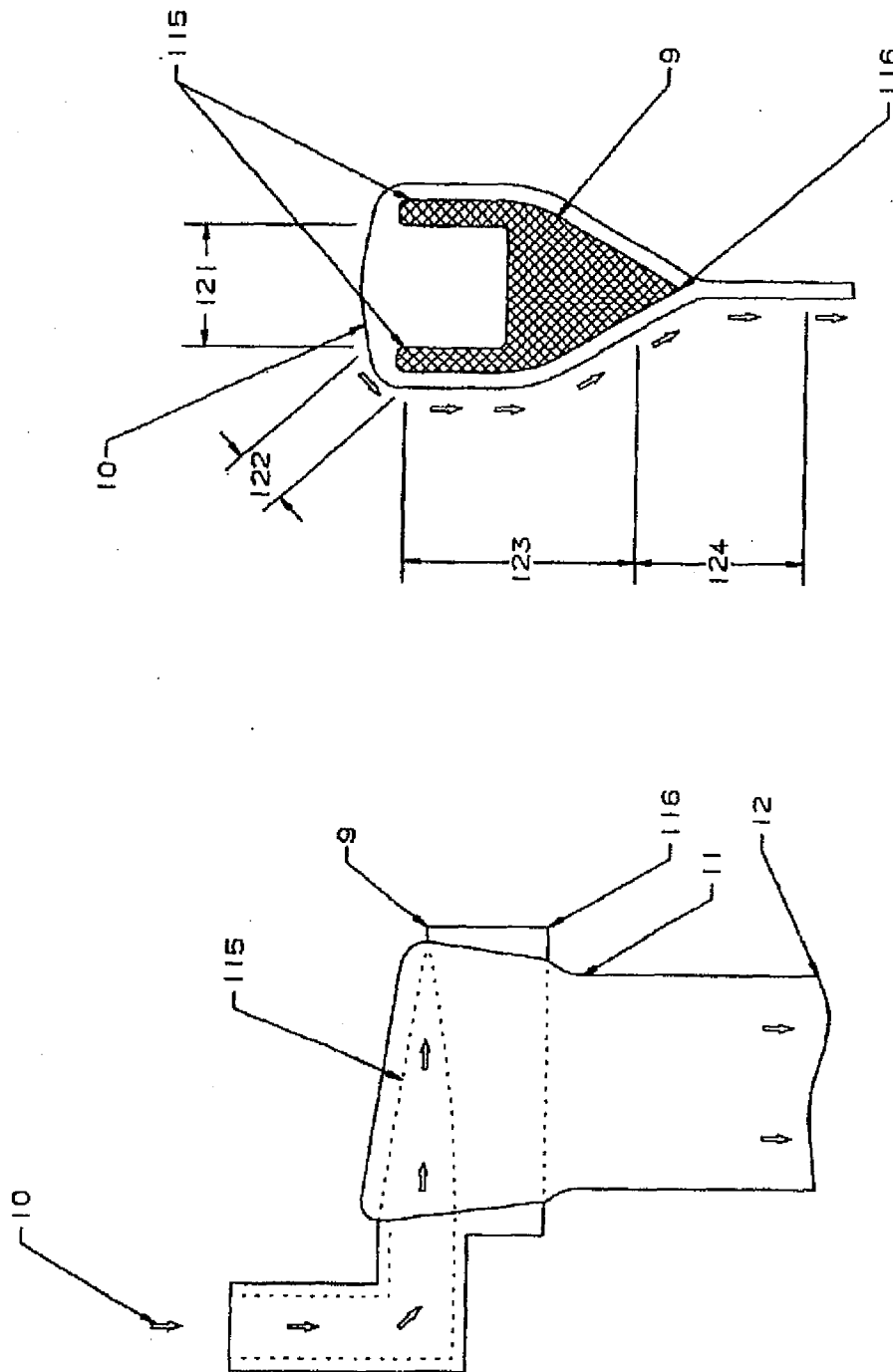


Figure 12B

Figure 12A

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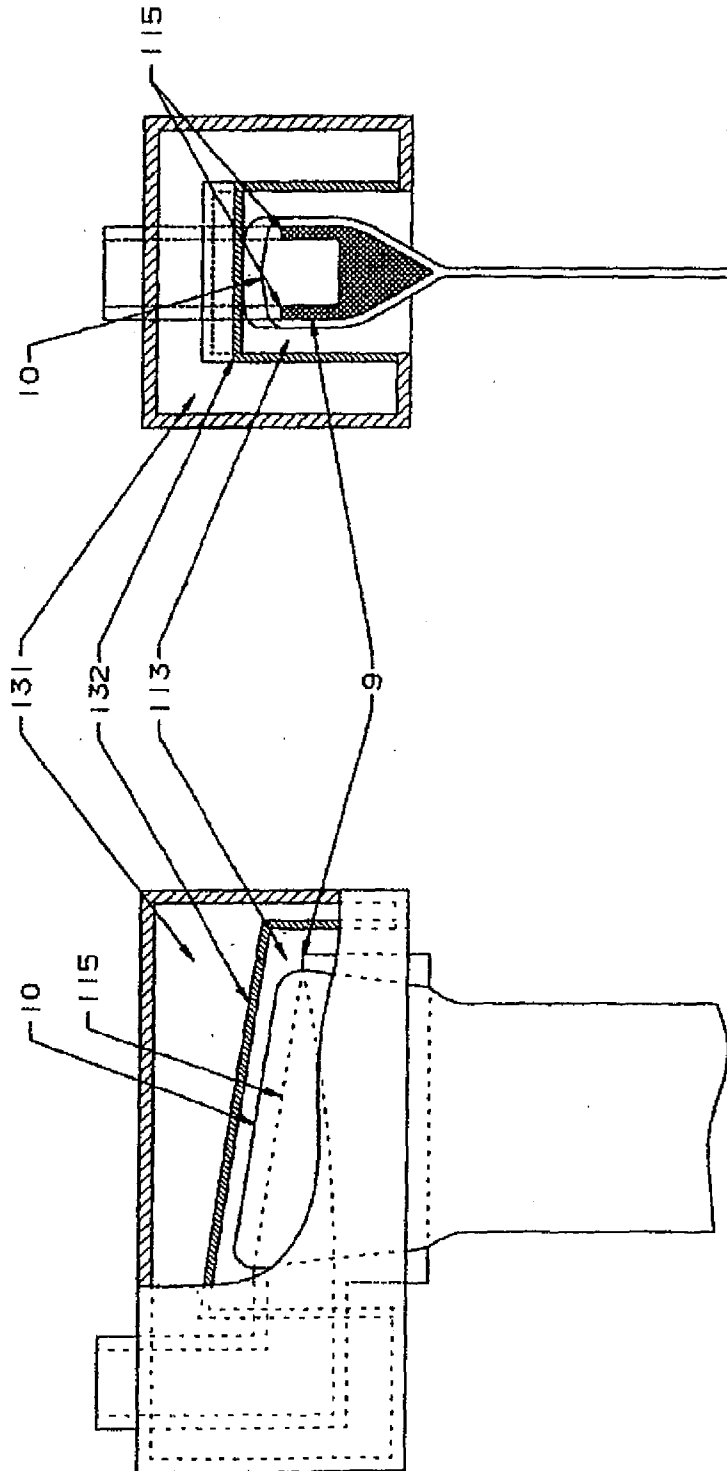


Figure 13B

Figure 13A

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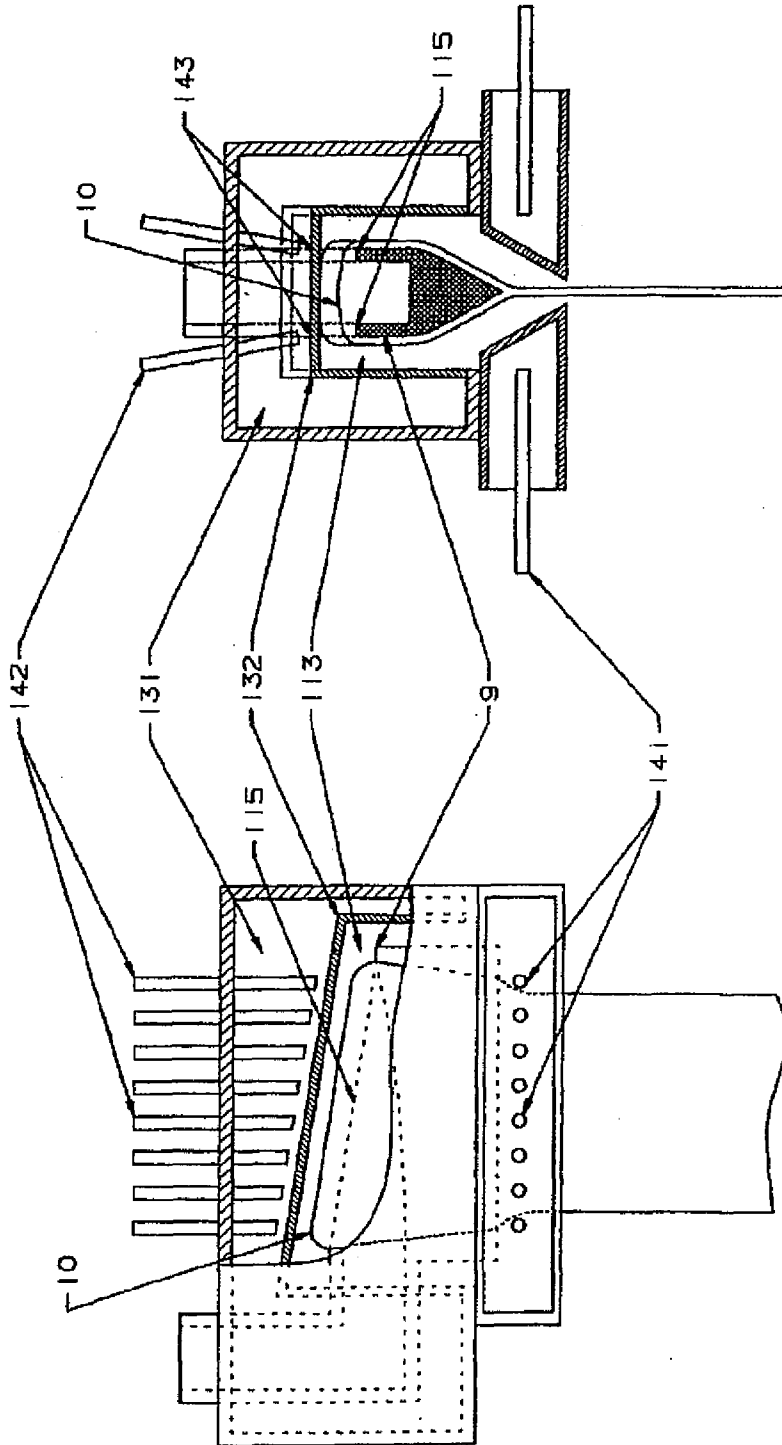


Figure 14B

Figure 14A

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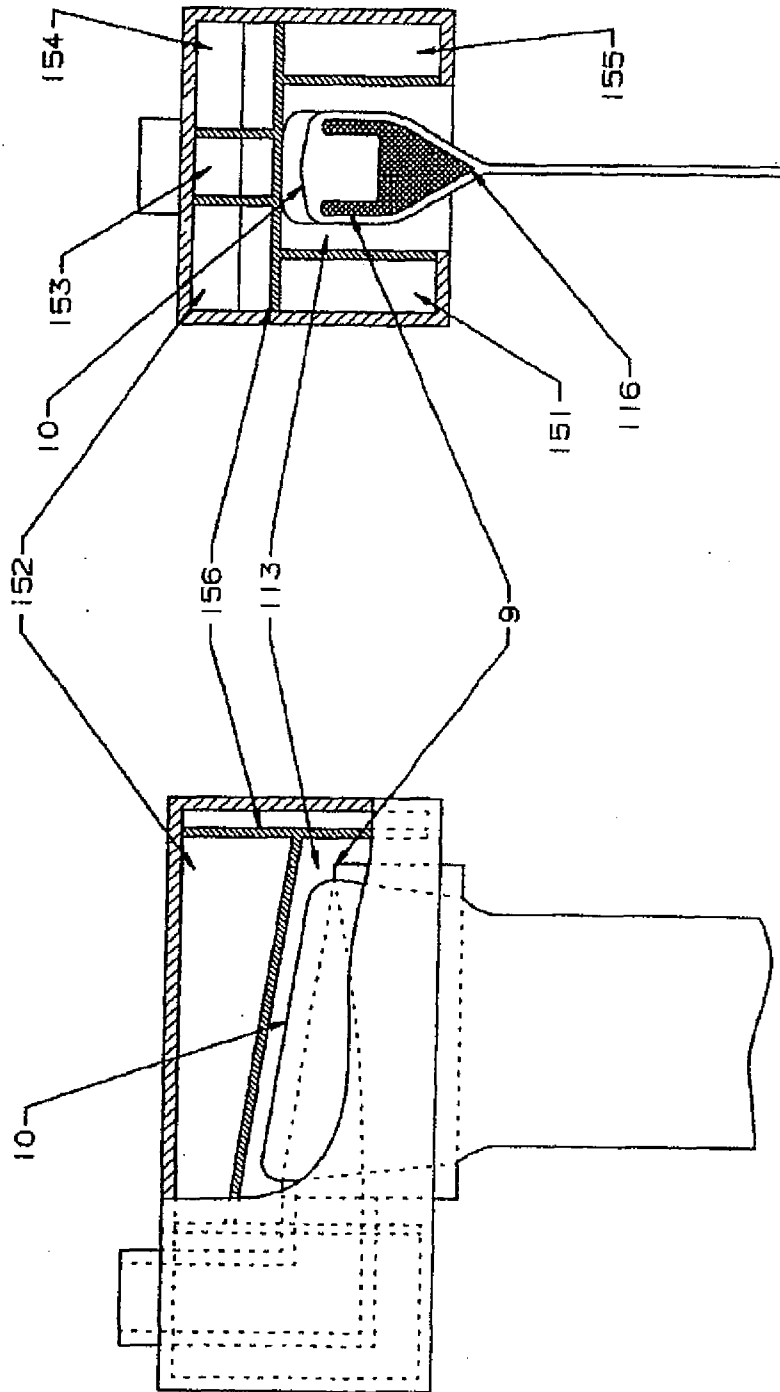


Figure 15A

Figure 15B

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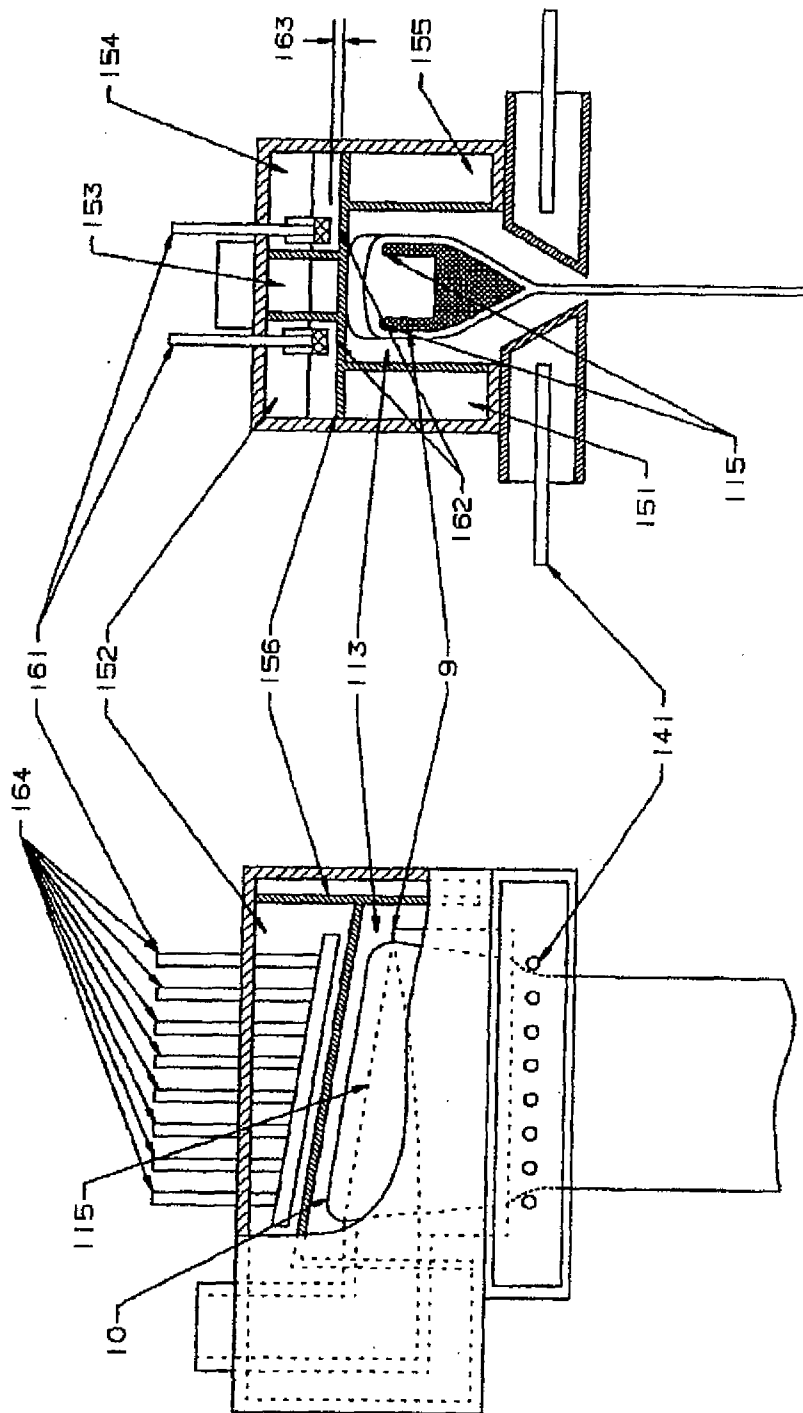


Figure 16B

Figure 16A

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PRIOR ART

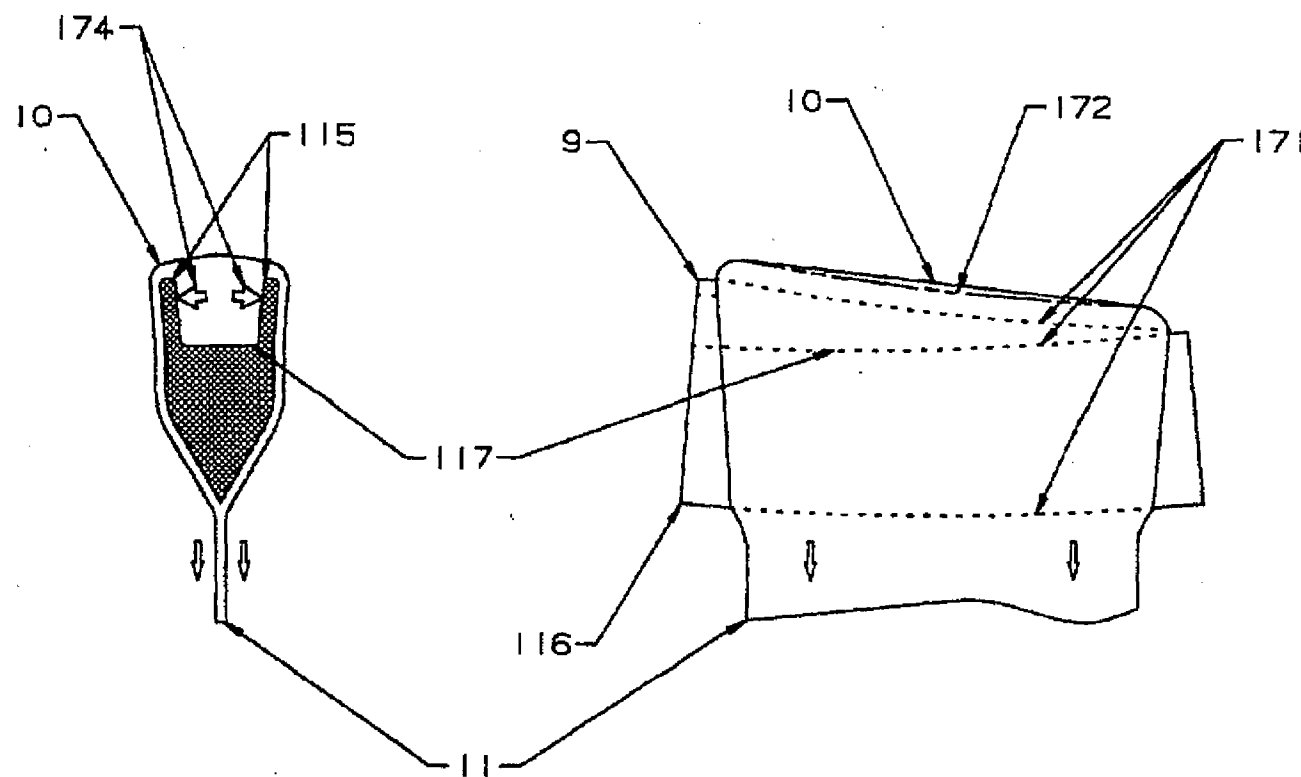
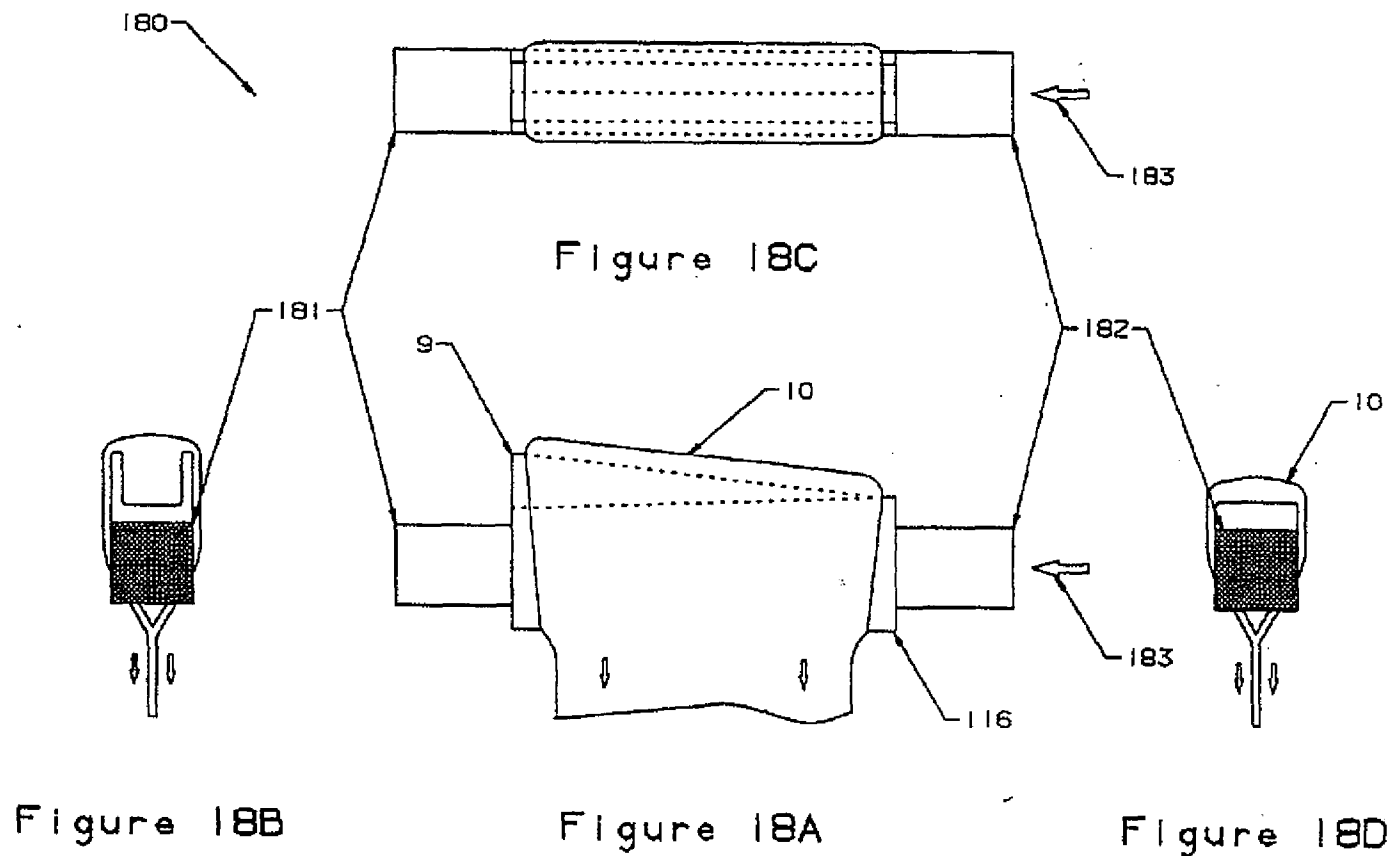


Figure 17B

Figure 17A

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PRIOR ART



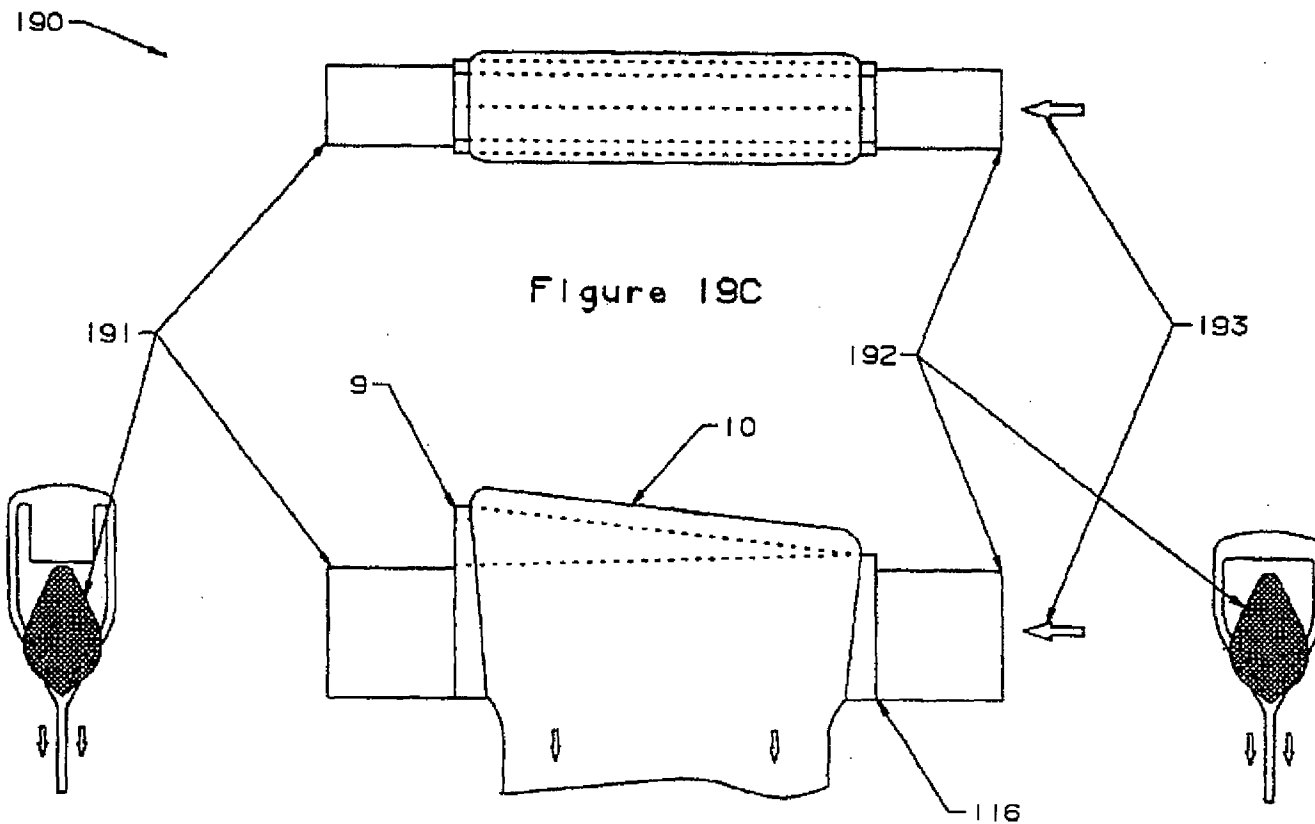
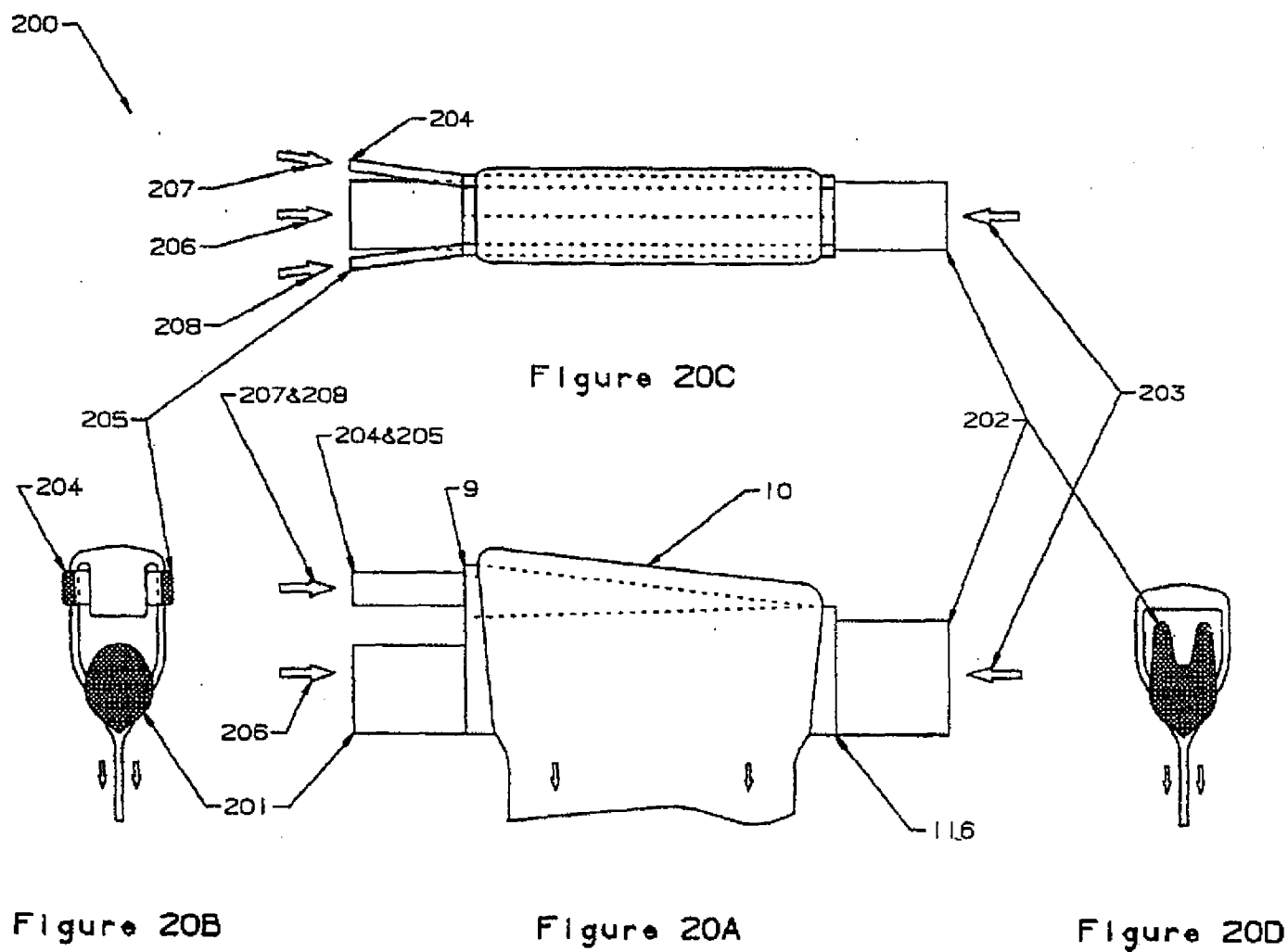


Figure 19B

Figure 19A

Figure 19D



PRIOR ART

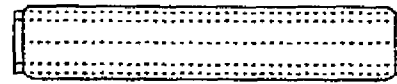


Figure 21B



Figure 21C



Figure 21D

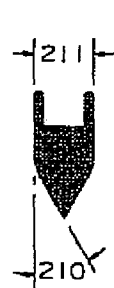


Figure 21E



Figure 21F



Figure 21G

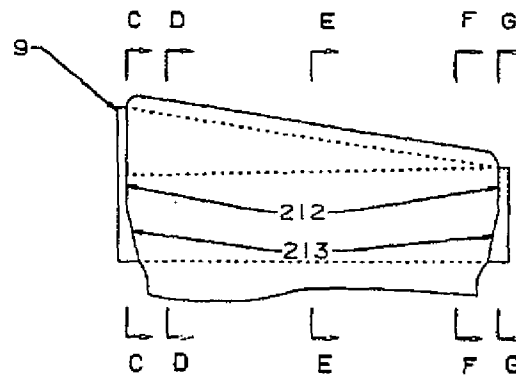


Figure 21A

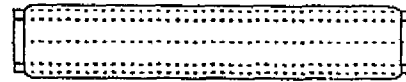


Figure 22B

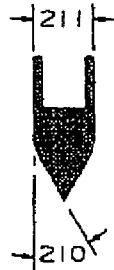
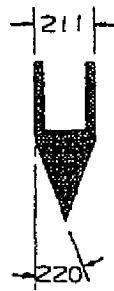


Figure 22C

Figure 22D

Figure 22E

Figure 22F

Figure 22G

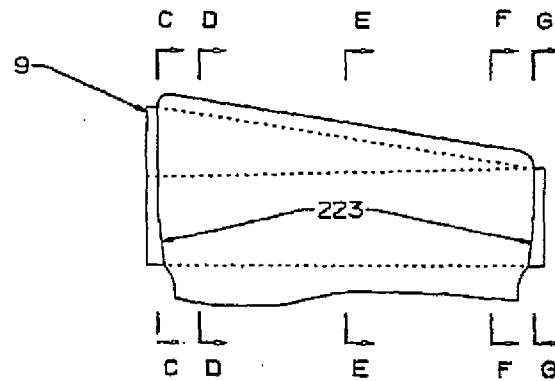


Figure 22A

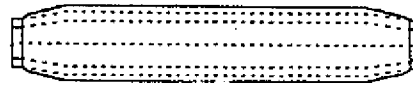


Figure 23B

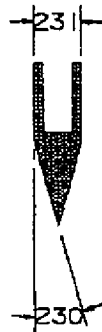


Figure 23C



Figure 23D



Figure 23E



Figure 23F



Figure 23G

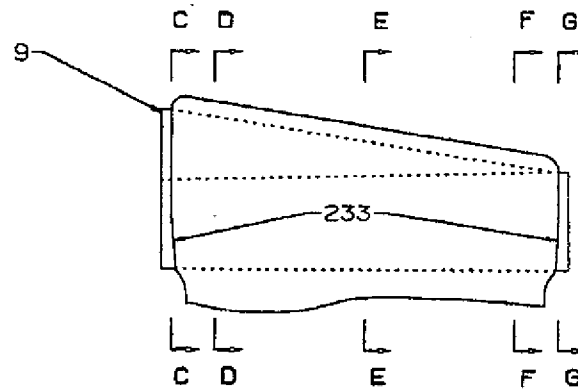


Figure 23A

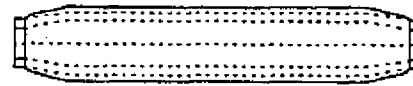


Figure 24B



Figure 24C



Figure 24D

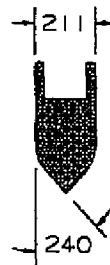


Figure 24E



Figure 24F



Figure 24G

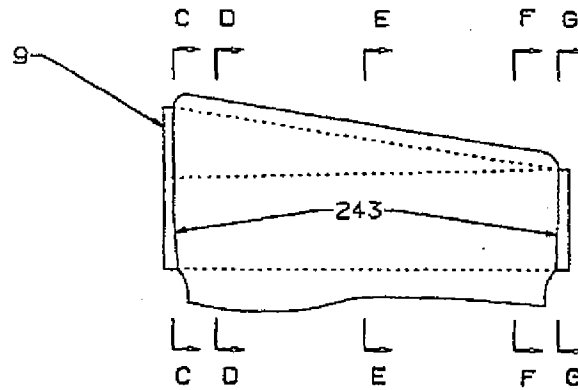


Figure 24A

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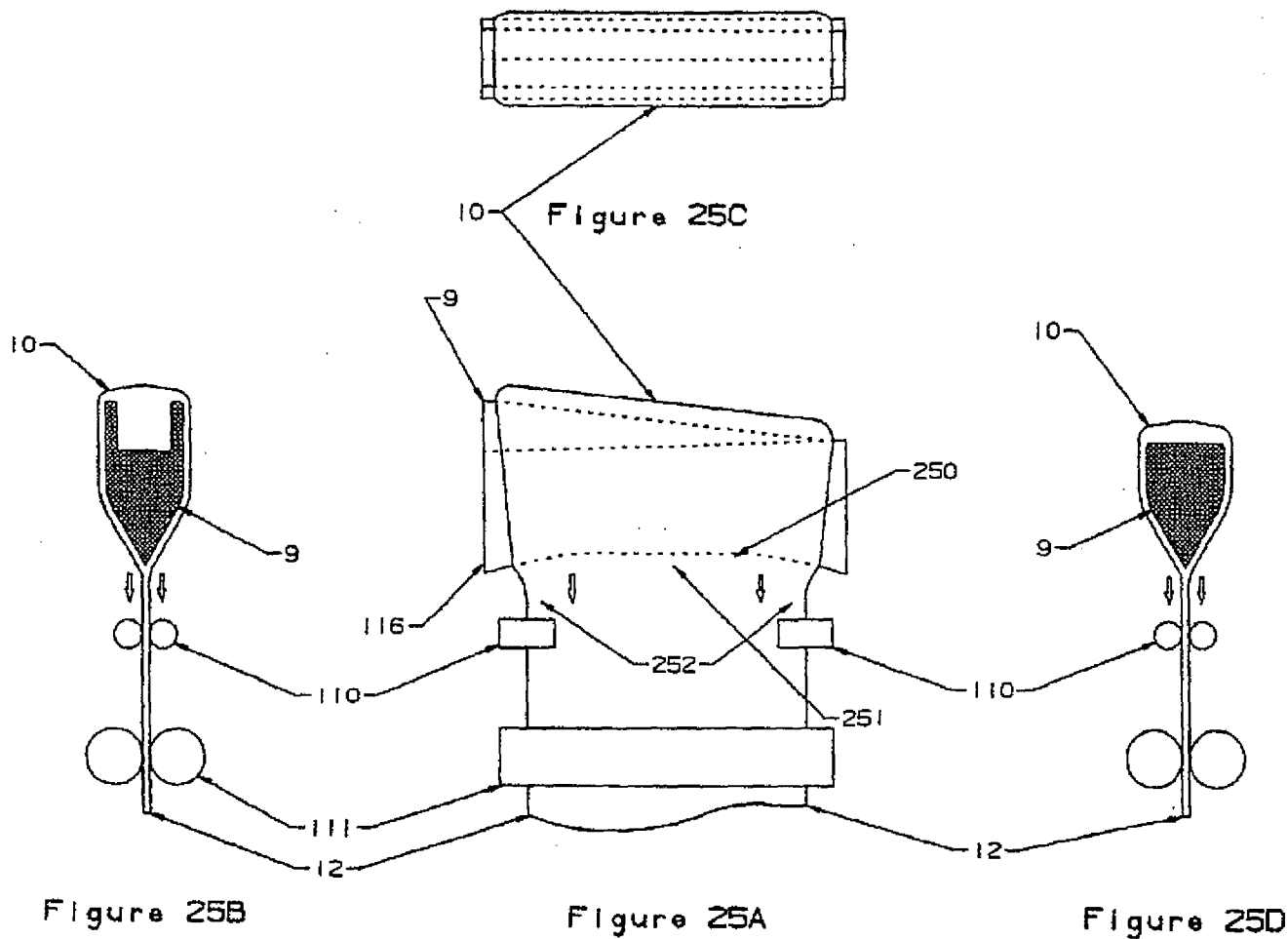
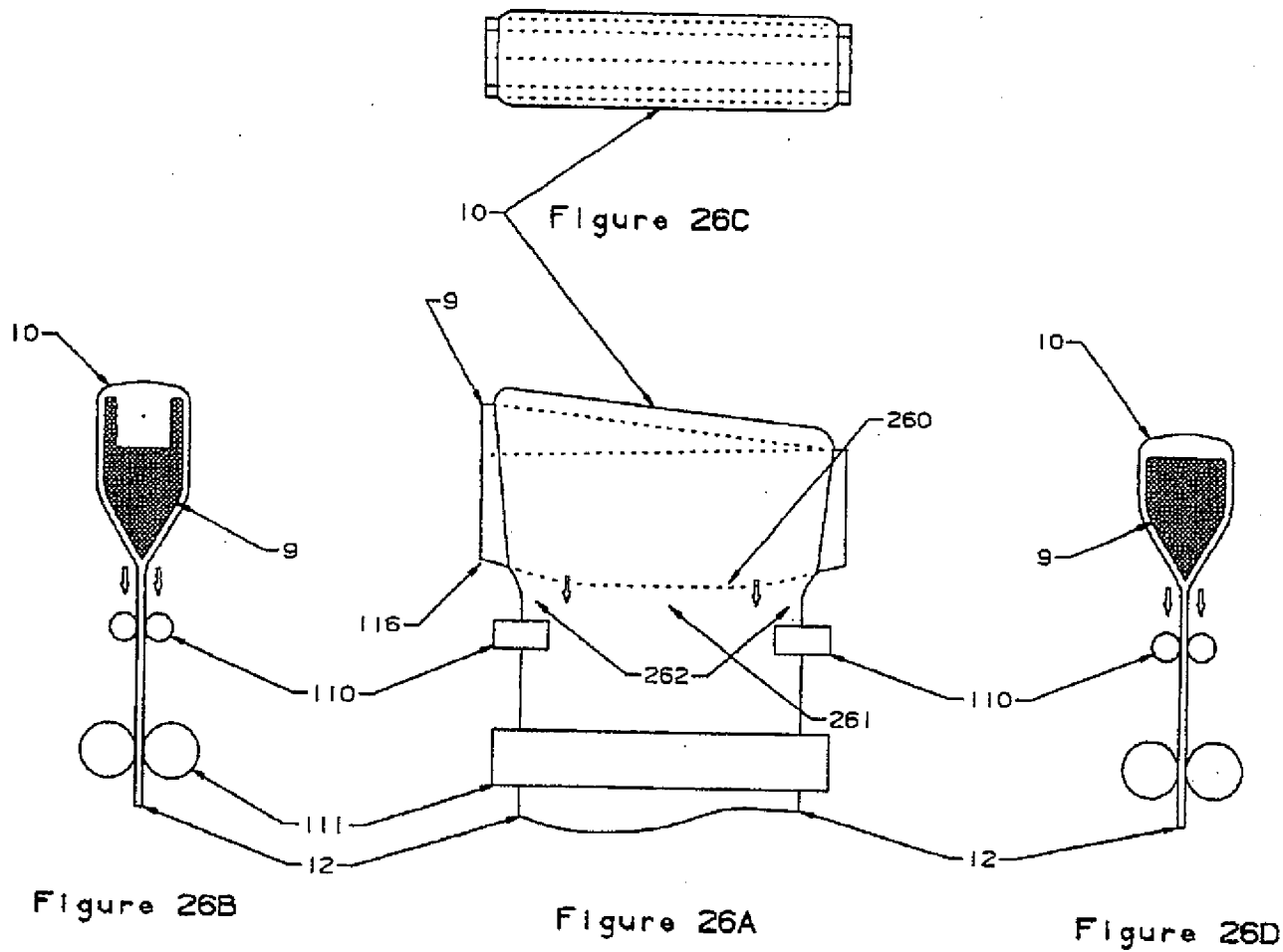
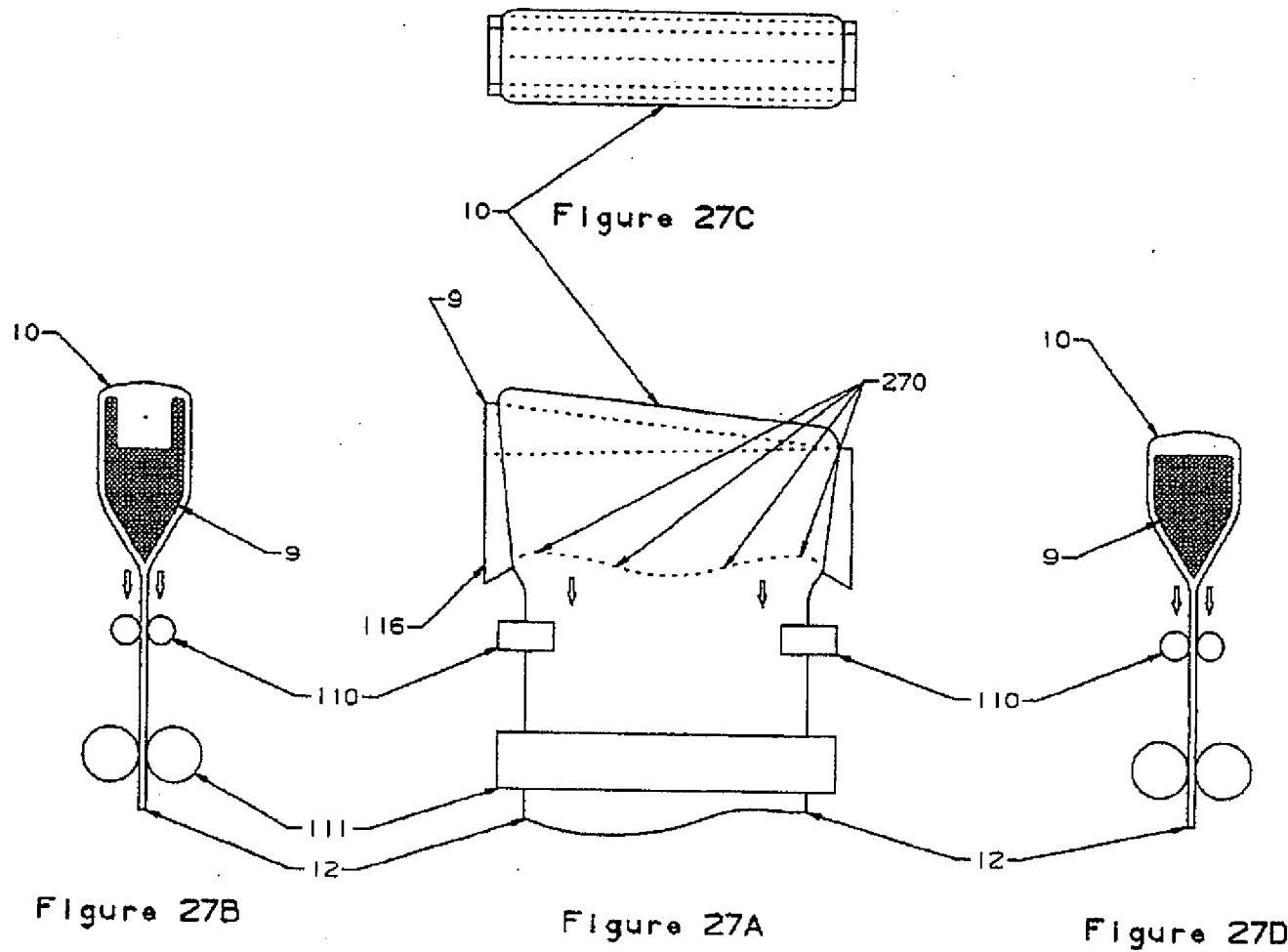


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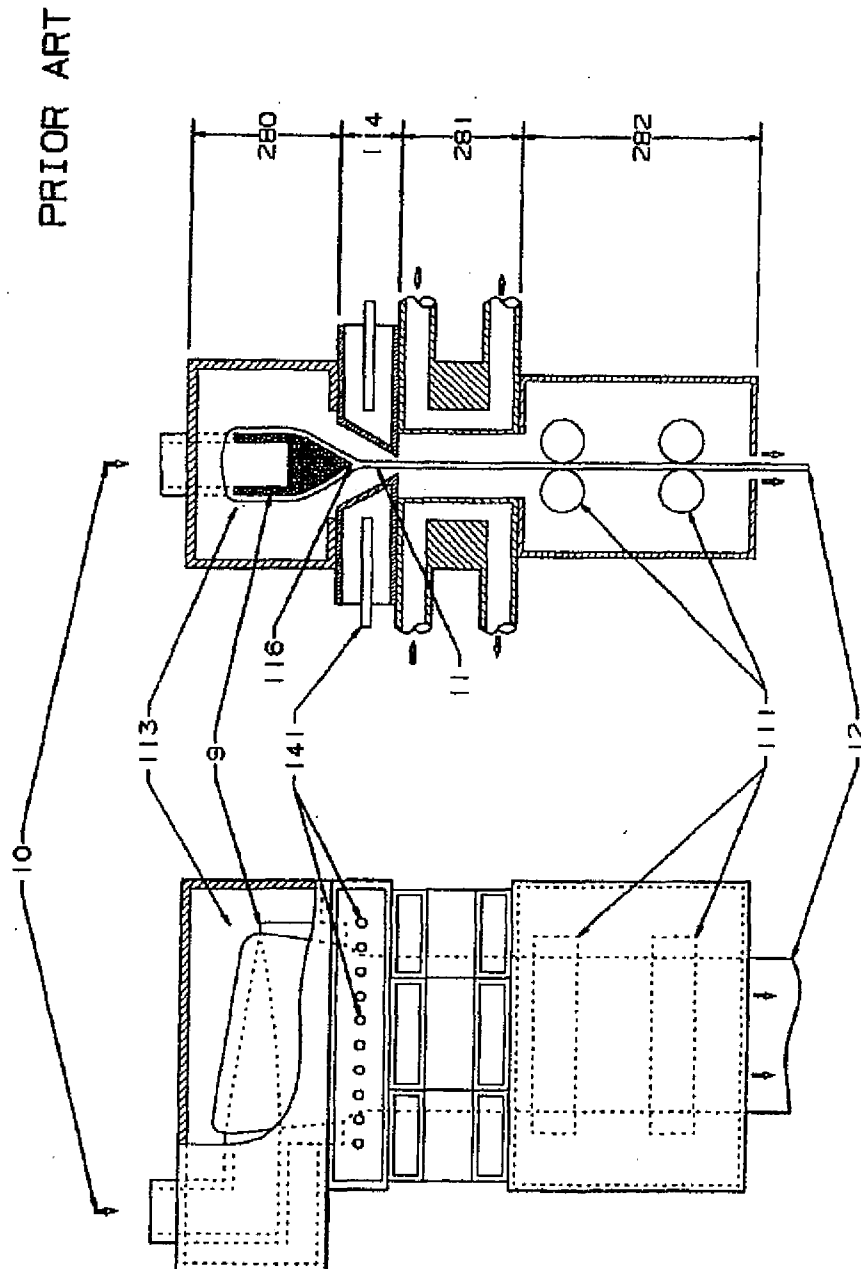


Figure 28B

Figure 28A

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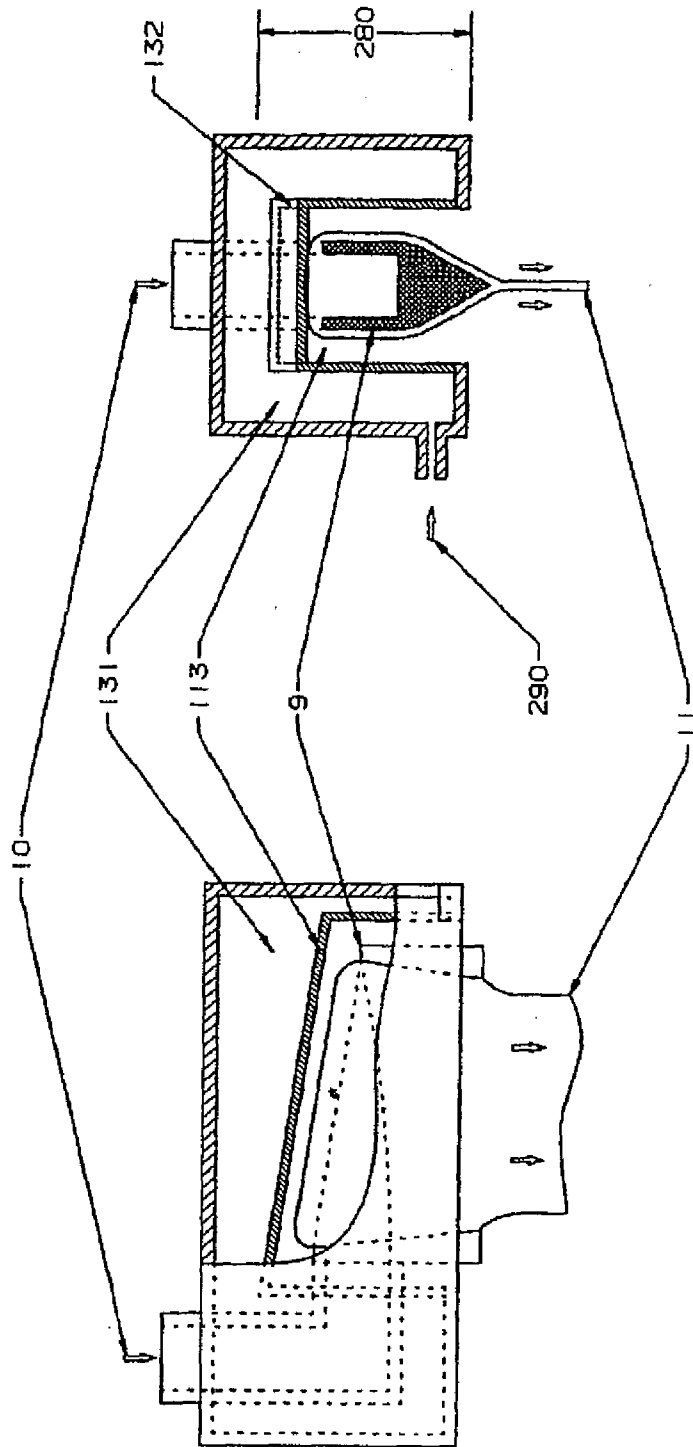


Figure 29B

Figure 29A

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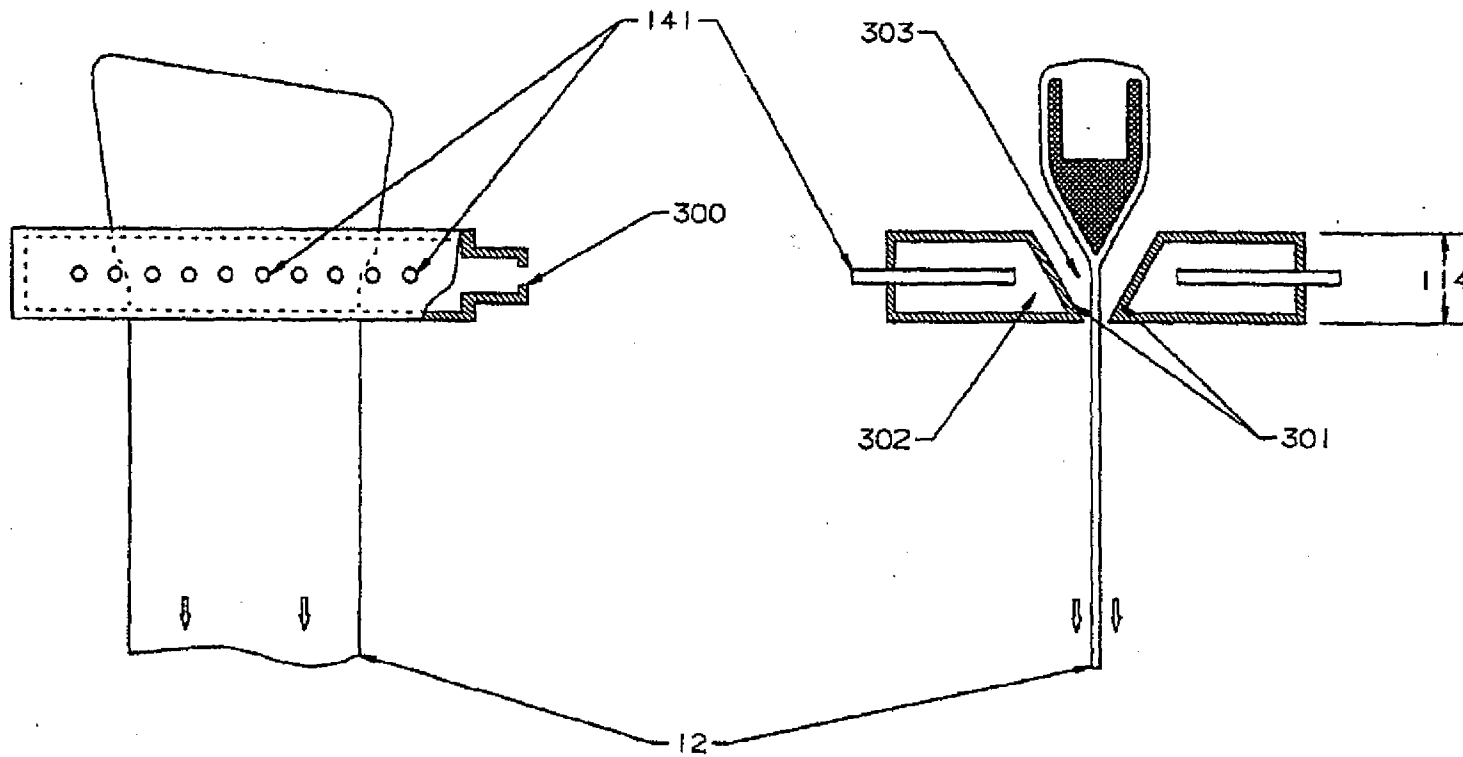


Figure 30A

Figure 30B

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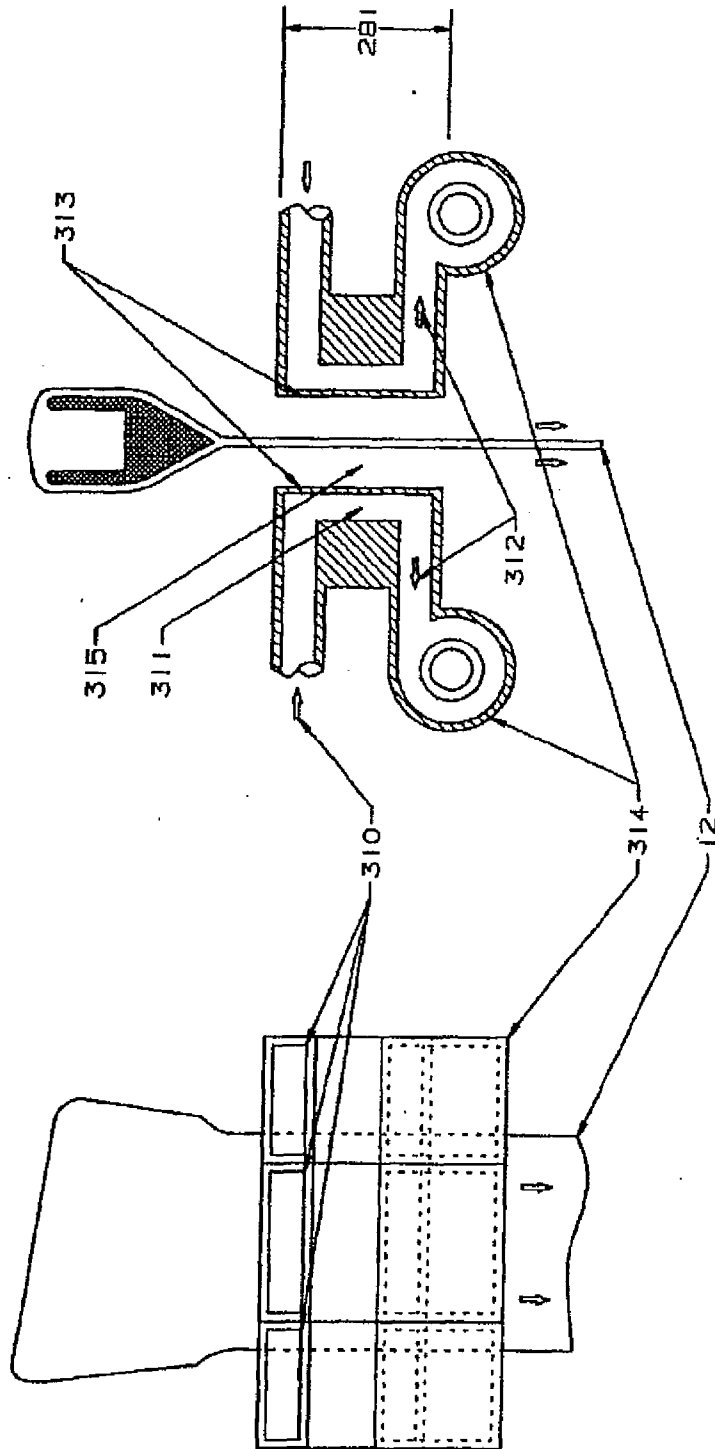


Figure 31B

Figure 31A

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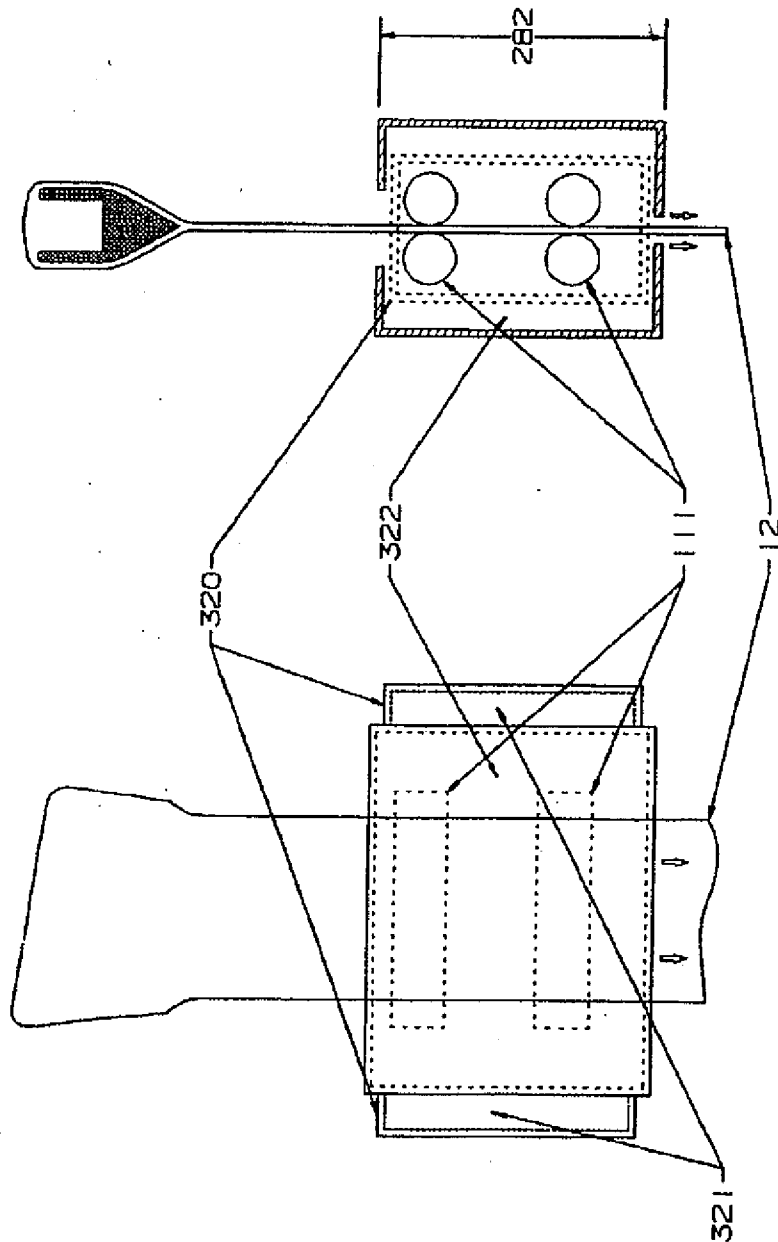


Figure 32B

Figure 32A

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**OVERFLOW DOWNDRAWN GLASS
FORMING METHOD AND APPARATUS****REFERENCE TO RELATED APPLICATIONS**

This application claims an invention that was disclosed in one of the following provisional applications:

- 1) Provisional Application No. 60/310,989, filed Aug. 8, 2001, entitled "SHEET GLASS FORMING DEVICE";
- 2) Provisional Application No. 60/316,676, filed Aug. 31, 2001, entitled "SHEET GLASS FORMING DEVICE";
- 3) Provisional Application No. 60/318,726, filed Sep. 12, 2001, entitled "SHEET GLASS FORMING APPARATUS";
- 4) Provisional Application No. 60/318,808, filed Sep. 13, 2001, entitled "SHEET GLASS FORMING APPARATUS";
- 5) Provisional Application No. 60/345,464, filed Jan. 3, 2002, entitled "SHEET GLASS FORMING APPARATUS"; and
- 6) Provisional Application No. 60/345,465, filed Jan. 3, 2002, entitled "SHEET GLASS FORMING APPARATUS".

The benefit under 35 USC §119(e) of the United States provisional applications is hereby claimed, and the aforementioned applications are hereby incorporated herein by reference.

This application claims an invention related to U.S. application Ser. No. 09/851,627, filed May 9, 2001, entitled "SHEET GLASS FORMING APPARATUS". The aforementioned application is hereby incorporated by reference.

BACKGROUND OF THE INVENTION**1. Field of the Invention**

The invention pertains generally to the manufacture of glass sheets, and, more particularly, to glass sheets formed from an overflow process.

2. Description of Related Art

The glass that is used for semiconductor powered display applications, and particularly for TFT/LCD display devices that are widely used for computer displays, must have very high surface quality to allow the successful application of semiconductor type material. Sheet glass made using the apparatus of U.S. Pat. No. 3,338,696, assigned to Corning, Inc., makes the highest quality glass as formed and does not require post-processing. The Corning patent makes glass by a manufacturing process termed: "The Overflow Process". Glass made using other processes requires grinding and/or polishing and thus does not have as fine a surface finish. The glass sheet must also conform to stringent thickness variation and warp specifications. The fine surface finish is formed from virgin glass primarily from the center of the glass stream. This glass has not been in contact with foreign surfaces since the stirring operation.

The teachings of U.S. Pat. No. 3,338,696 are still the state of the art as practiced today. However, the apparatus has limitations.

A major drawback of the apparatus of "The Overflow Process" is that, even though it makes excellent glass over most of the surface, the surface of the glass sheet nearest the inlet is composed of glass that has flowed in proximity to the feeding pipe surfaces and therefore is subject to lower quality.

Another drawback of the apparatus of "The Overflow Process" is that, even though it makes excellent glass

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during stable operating conditions, it recovers from transient conditions very slowly. This is caused in part by quiescent zones of glass flow in the pipes conducting the glass from the stirring device to the apparatus when these pipes are designed using traditional practice. During unintended process transient these quiescent zones slowly bleed glass of a previous material composition into the main process stream of glass causing defects. These defects eventually subside when the process stabilizes; however, there is a period of time where the quality of the glass sheet is substandard.

Yet another drawback of the apparatus of "The Overflow Process" is the limited means for controlling the thickness of the formed sheet. The selective cooling of the glass with respect to width as the sheet is formed is not provided in current practice.

The thickness control system of U.S. Pat. No. 3,682,609 can compensate for small thickness errors, but it can only redistribute the glass over distances on the order of 5-10 cm.

Another drawback of the apparatus of "The Overflow Process" is that the forming apparatus deforms during a manufacturing campaign in a manner such that the glass sheet no longer meets the thickness specification. This is a primary cause for premature termination of the production run.

A further drawback of the apparatus of "The Overflow Process" is that surface tension and body forces have a major effect on the molten glass flow down the external sides of the forming apparatus causing the sheet to be narrower than the forming apparatus and the edges of the formed sheet to have thick beads.

U.S. Pat. No. 3,451,798 provides for edge directors which endeavor to compensate for the surface tension effects but are in reality a correction for problems created by restricting the forming apparatus cross-section to a single profile on its external surface.

Another drawback of the prior art is that the glass sheet is not inherently flat when drawn from the forming apparatus.

Yet another drawback of the apparatus of "The Overflow Process" is that the drawing of the sheet from the bottom of the apparatus has a propensity to have a cyclic variation in sheet thickness. This cyclic thickness variation is a strong function of uncontrolled air currents, which tend to become more prevalent as the equipment ages during a production campaign. As the apparatus ages, air leaks develop through cracks in material and assorted openings caused by differential expansion.

Therefore, there is a need in the art for an apparatus which overcomes the shortcomings of the prior art.

SUMMARY OF THE INVENTION

In a preferred embodiment of the present invention, all the glass that forms the surface of the useful area of the sheet is virgin glass, which is not contaminated by flow in proximity to a refractory or refractory metal surface after the stirring operation. In addition, this embodiment significantly reduces inhomogeneities in the glass that forms the sheet by relocating or eliminating the regions of quiescent flow in the piping between the stirring device and the sheet glass forming apparatus.

In another preferred embodiment, this invention introduces a precise thermal control system to redistribute the flow of molten glass at the weirs which is the most critical area of the forming process. This thermal control effectively counteracts the degradation of the sheet forming apparatus which inevitably occurs during a production campaign.

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In yet another preferred embodiment, the invention introduces a counteracting force to these stresses on the trough in a manner such that the thermal creep which inevitably occurs has a minimum impact on the glass flow characteristics of the forming trough. This embodiment is designed such that this counteracting force is maintained through an extended period of the production campaign. Thus, sheet glass may be manufactured for a longer time with the same forming trough.

Another preferred embodiment creates a variable external cross-section which alters the direction and magnitude of the surface tension and body force stresses and thus, reduces the adverse influence of surface tension and body forces on sheet width.

In an alternative preferred embodiment, the glass is preferentially cooled across its width to create forming stresses during solidification, which ensure that the glass sheet drawn is inherently flat.

In a further preferred embodiment, this invention adjusts the internal pressure in each of the major components of the forming apparatus such that the pressure difference across any leakage path to the forming zone is essentially zero. Therefore, air leakage in the apparatus is minimized even though the cracks and openings exist during initial operation and develop during manufacturing.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates the principle parts of "The Overflow Process" glass sheet manufacturing system.

FIG. 2A shows a side view of "The Overflow Process" as known in the prior art.

FIG. 2B shows a cross-section of the glass flow in the downcomer pipe across lines B—B of FIG. 2A.

FIG. 2C shows a cross-section across lines C—C of FIG. 2A, where the glass flow in the downcomer pipe appears in the sheet for "The Overflow Process".

FIG. 3A shows a side view of a surface flow distribution device in a preferred embodiment of the present invention.

FIG. 3B shows a top view of a surface flow distribution device in a preferred embodiment of the present invention.

FIG. 4A shows a side view of a submerged flow distribution device in a preferred embodiment of the present invention.

FIG. 4B shows a top view of a submerged flow distribution device in a preferred embodiment of the present invention.

FIG. 5A shows a side view of "The Overflow Process" in an embodiment of the present invention.

FIG. 5B shows the glass flow in the downcomer pipe across lines B—B of FIG. 5A when a flow distribution device is used.

FIG. 5C shows a cross-section across lines C—C of FIG. 5A, where the glass flow in the downcomer pipe appears in the sheet when a flow distribution device is used.

FIG. 6 shows a bowl with an inclined axis which diffuses the quiescent flow zone at the bowl nose in a preferred embodiment of the present invention.

FIG. 7A shows the top view of a bowl with side inflow which relocates the quiescent flow zone from the bowl nose to the bowl side in a preferred embodiment of the present invention.

FIG. 7B shows a side view of FIG. 7A.

FIG. 7C shows the top view of a bowl with side inflow which relocates the quiescent flow zone from the bowl nose

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to a location approximately 45 degrees to the side with respect to the centerline of the forming apparatus in a preferred embodiment of the present invention.

FIG. 7D shows a side view of FIG. 7C.

FIG. 8 illustrates a bowl in "The Overflow Process" as known in the prior art.

FIG. 9A shows a downcomer pipe feeding the forming apparatus inlet with minimum quiescent flow in a preferred embodiment of the present invention.

FIG. 9B shows a top view of FIG. 9A.

FIG. 9C shows a detail of the downcomer pipe to trough inlet pipe connection showing the glass flow pattern in a preferred embodiment of the present invention.

FIG. 10A shows the flow between the downcomer pipe and the forming apparatus inlet in "The Overflow Process" as known in the prior art.

FIG. 10B shows a top view of FIG. 10A.

FIG. 10C shows a detail of the downcomer pipe to trough inlet pipe connection showing the glass flow pattern as known in the prior art.

FIG. 11A shows the principle parts of a typical "Overflow Process" manufacturing system.

FIG. 11B shows a section of FIG. 11A.

FIG. 12A illustrates a side view of the glass flowing through the forming trough.

FIG. 12B shows a section through the center of the forming trough of FIG. 12A showing the cooling zones.

FIG. 13A shows a revised single heating chamber muffle design in a preferred embodiment of the present invention.

FIG. 13B shows a section of FIG. 13A.

FIG. 14A shows air cooling tubes to effect localized cooling to the molten glass as it passes over the weirs in a preferred embodiment of the invention.

FIG. 14B shows a section of FIG. 14A.

FIG. 15A shows a muffle with multiple heating chambers in a preferred embodiment of the invention.

FIG. 15B shows a section of FIG. 15A.

FIG. 16A shows radiant coolers which effect localized cooling to the molten glass as it passes over the weirs in a preferred embodiment of the invention.

FIG. 16B shows a section of FIG. 16A.

FIG. 17A illustrates how the prior art trough design deforms as a result of thermal creep.

FIG. 17B shows another view of FIG. 17A.

FIG. 18A shows the forming trough support system as known in the prior art.

FIG. 18B shows another view of FIG. 18A.

FIG. 18C shows another view of FIG. 18A.

FIG. 18D shows another view of FIG. 18A.

FIG. 19A shows single shaped compression blocks on each end of the trough in a preferred embodiment of the present invention.

FIG. 19B shows another view of FIG. 19A.

FIG. 19C shows another view of FIG. 19A.

FIG. 19D shows another view of FIG. 19A.

FIG. 20A shows a single shaped compression block on one end of the trough and multiple shaped compression blocks on the other end in a preferred embodiment of the present invention.

FIG. 20B shows another view of FIG. 20A.

FIG. 20C shows another view of FIG. 20A.

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FIG. 20D shows another view of FIG. 20A.
 FIG. 21A shows a trough design as known in the prior art.
 FIG. 21B shows a top view of FIG. 21A.
 FIG. 21C shows a cross-section of the trough design shown in FIG. 21A across lines C—C.
 FIG. 21D shows a cross-section of the trough design shown in FIG. 21A across lines D—D.
 FIG. 21E shows a cross-section of the trough design shown in FIG. 21A across lines E—E.
 FIG. 21F shows a cross-section of the trough design shown in FIG. 21A across lines F—F.
 FIG. 21G shows a cross-section of the trough design shown in FIG. 21A across lines G—G.
 FIG. 22A shows a reduced inverted slope at each end of the trough in a preferred embodiment of the present invention.
 FIG. 22B shows a top view of FIG. 22A.
 FIG. 22C shows a cross-section of the trough design shown in FIG. 22A across lines C—C.
 FIG. 22D shows a cross-section of the trough design shown in FIG. 22A across lines D—D.
 FIG. 22E shows a cross-section of the trough design shown in FIG. 22A across lines E—E.
 FIG. 22F shows a cross-section of the trough design shown in FIG. 22A across lines F—F.
 FIG. 22G shows a cross-section of the trough design shown in FIG. 22A across lines G—G.
 FIG. 23A shows an alternate embodiment of the present invention with further modified ends.
 FIG. 23B shows a top view of FIG. 23A.
 FIG. 23C shows a cross-section of the trough design shown in FIG. 23A across lines C—C.
 FIG. 23D shows a cross-section of the trough design shown in FIG. 23A across lines D—D.
 FIG. 23E shows a cross-section of the trough design shown in FIG. 23A across lines E—E.
 FIG. 23F shows a cross-section of the trough design shown in FIG. 23A across lines F—F.
 FIG. 23G shows a cross-section of the trough design shown in FIG. 23A across lines G—G.
 FIG. 24A shows an alternate embodiment of the present invention with the potential for increased structural stiffness.
 FIG. 24B shows a top view of FIG. 24A.
 FIG. 24C shows a cross-section of the trough design shown in FIG. 24A across lines C—C.
 FIG. 24D shows a cross-section of the trough design shown in FIG. 24A across lines D—D.
 FIG. 24E shows a cross-section of the trough design shown in FIG. 24A across lines E—E.
 FIG. 24F shows a cross-section of the trough design shown in FIG. 24A across lines F—F.
 FIG. 24G shows a cross-section of the trough design shown in FIG. 24A across lines G—G.
 FIG. 25A shows a forming trough with a convex upward forming root which solidifies the center glass before the edge glass in a preferred embodiment of the present invention.
 FIG. 25B shows another view of FIG. 25A.
 FIG. 25C shows another view of FIG. 25A.
 FIG. 25D shows another view of FIG. 25A.
 FIG. 26A shows a forming trough with a convex downward forming root which solidifies the edge glass before the center glass in a preferred embodiment of the present invention.

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FIG. 26B shows another view of FIG. 26A.
 FIG. 26C shows another view of FIG. 26A.
 FIG. 26D shows another view of FIG. 26A.
 FIG. 27A shows a forming trough with a complexly shaped forming root to solidify the glass in a unique manner over its width in a preferred embodiment of the present invention.
 FIG. 27B shows another view of FIG. 27A.
 FIG. 27C shows another view of FIG. 27A.
 FIG. 27D shows another view of FIG. 27A.
 FIG. 28A illustrates the cooling process in "The Overflow Process" glass sheet forming system as known in the prior art.
 FIG. 28B shows a section of FIG. 28A.
 FIG. 29A shows how the pressure in the muffle zone may be controlled to minimize leakage in a preferred embodiment of the present invention.
 FIG. 29B shows a section of FIG. 29A.
 FIG. 30A shows how the pressure in the muffle door zone may be controlled to minimize leakage in a preferred embodiment of the present invention.
 FIG. 30B shows a section of FIG. 30A.
 FIG. 31A shows how the pressure in the transition zone may be controlled to minimize leakage in a preferred embodiment of the present invention.
 FIG. 31B shows a section of FIG. 31A.
 FIG. 32A shows how the pressure in the annealer and pulling machine zone may be controlled to minimize leakage in a preferred embodiment of the present invention.
 FIG. 32B shows a section of FIG. 32A.

DETAILED DESCRIPTION OF THE INVENTION

The flow dynamics of this invention are such that the outside surfaces of the glass sheet are formed from thoroughly mixed virgin glass that comes from the center of the glass stream flowing into the forming apparatus and thus has not contacted a refractory or refractory metal surface. This produces the highest possible surface quality. This pristine surface is essential for the manufacture of LCD/TFT semiconductor display devices. In addition, the flow dynamics in all embodiments of this invention are such that the flow rate of molten glass to the forming wedge at the bottom of the forming trough is substantially uniform over its width.

Referring to FIGS. 1, 11A and 11B, a typical "Overflow Process" manufacturing system (1) is shown. The glass (10) from the melting furnace (2) and forehearth (3), which must be of substantially uniform temperature and chemical composition, feeds a stirring device (4). The stirring device (4) thoroughly homogenizes the glass. The glass (10) is then conducted through a bowl inlet pipe (5), into a bowl (6), and down into the downcomer pipe (7), through the joint (14) between the downcomer pipe (7) and the forming apparatus inlet pipe (8), to the inlet of the overflow trough (9). While flowing from the stirring device (4) to the trough (9), the glass (10), especially that which forms the sheet surface, must remain homogeneous. The normal purpose of the bowl (6) is to alter the flow direction from horizontal to vertical and to provide a means for stopping the flow of glass (10). A needle (13) is provided to stop glass flow. The normal function of the joint (14) between the downcomer pipe (7) and the trough inlet pipe (8) is to allow for removal of the sheet glass forming apparatus for service as well as a means of adjustment of the process equipment.

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The molten glass (10) from the melting furnace and forehearth, which must be of substantially uniform temperature and chemical composition, enters the forming apparatus through the inlet pipe (8) to the sheet forming trough (9). The inlet pipe (8) is preferably shaped to control the velocity distribution of the incoming molten glass flow. The glass sheet forming apparatus, which is described in detail in both U.S. Pat. No. 3,338,696 and patent application Ser. No. 09/851,627, herein incorporated by reference, is a wedge shaped forming device (9). Straight sloped weirs (115), substantially parallel with the pointed edge of the wedge (root) (116), form each side of the trough. The bottom of the trough (117) and sides of the trough (118) are contoured in a manner to provide even distribution of glass to the top of each side weir (115). The glass then flows over the top of each side weir (115), down each side of the wedge shaped forming device (9), and joins at the pointed edge of the root (116), to form a sheet of molten glass (11). The sheet of molten glass (11) is then cooled as it is pulled off the root (116) by pulling rollers (111) to form a solid glass sheet (12) of substantially uniform thickness. Edge rollers (110) may also be used to draw the molten glass sheet (11). In the prior art, the forming trough (9) is encased within a muffle whose purpose is to control the temperature of the forming trough (9) and the molten glass (10). It is normal practice to maintain a uniform temperature in the muffle chamber (113) surrounding the forming trough (9). Cooling the glass as it transitions from the molten state to the solid state must be carefully controlled. This cooling process starts on the lower part of the forming apparatus (9) just above the root (116), and continues as the molten glass sheet passes through the muffle door zone (114). The molten glass is substantially solidified by the time it reaches the pulling rollers (111). The molten glass forms a solid glass sheet (12) of substantially uniform thickness.

Altering Glass Flow Distribution

Referring also to FIGS. 2 through 10, a preferred embodiment of the present invention alters the flow path at the inlet of the sheet glass forming apparatus to improve surface quality. It also facilitates more uniform flow of glass through the piping that conducts the glass from the stirring device to the sheet glass forming apparatus.

U.S. Pat. No. 3,338,696 considers only the glass flow within the forming trough. U.S. Pat. No. 3,338,696 also claims that the entire sheet surface is formed from virgin glass, which has not been adversely effected by contact with a foreign surface. This is not entirely correct as the sheet formed on the inlet end of the trough has flowed on the piping system front surface. A flow distribution device is added at the trough inlet in this invention to ensure that all of the useable sheet surface is formed from virgin glass. The piping system between the glass stirring device and the glass sheet forming apparatus is modified from traditional practice in the bowl and at the connection between the downcomer pipe and the forming apparatus inlet pipe. The flow through the bowl is altered, either eliminating or relocating the quiescent flow zone that normally forms at the front top surface of the bowl. The downcomer pipe is not submerged in the forming apparatus inlet pipe glass thus eliminating the quiescent flow zone between the pipes.

FIGS. 2A through 2C illustrate where the glass (10) flowing in the downcomer feed pipe (7) ends up in the formed glass sheet in the prior art "Overflow Process". The glass flow in proximity to the sides (21) of the downcomer pipe (7) ends up in the center of the drawn sheet. The flow (23) in proximity to the front surface of the downcomer pipe (7) is distributed over the entire glass surface, however, it is

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most concentrated on the approximate one third of the sheet at the inlet end. This surface glass (23) is subject to disruption by the downcomer pipe surface and by the glass in the quiescent zones in the bowl (6) and at the downcomer pipe (7) to inlet pipe (8) connection (14). The surface of the remaining substantially two thirds of the sheet is formed from virgin interior glass (22). Two other portions of the glass flow (24) which are symmetrically offset from the front surface at an angle of approximately 45 degrees end up forming the near end unusable edge section (25) at the inlet end of the sheet. Another portion (26) centered at the back surface at an angle of approximately 180 degrees proceeds to the far end unusable edge section (27).

FIGS. 3A and 3B show an embodiment of the glass sheet forming apparatus (31) with an inflow pipe (8), a flow distribution device (32) (which is a subject of this invention) located at the trough inlet surface, and the glass sheet forming apparatus body (9). The flow distribution device (32) interrupts the glass surface flow and diverts it to the surface in the edge of the sheet. Glass from the center of the downcomer pipe flow stream then comes to the surface of the forming trough to form the surface of the useable portion of the glass sheet (11). Note that ten to twenty percent of the sheet at each edge is normally unusable for various reasons.

FIGS. 4A and 4B show an alternative embodiment of the glass sheet forming apparatus (41), which performs the same function as the embodiment in FIG. 3 except that the surface flow distribution device (42) is located under the surface of the glass (10) and redistributes the surface flow in a more subtle but equally effective manner. The glass flow (10) that forms the unusable inlet edge of the sheet, flows through the center slot (43) in the flow distribution device (42). The glass (which flows through this center slot) is the glass that has been in proximity to the front surface of the downcomer pipe. Glass from the center of the downcomer pipe then flows to the trough surface to form the surface of the useable portion of the sheet (11). Other glass that flows in proximity to the surface of the downcomer pipe remains submerged.

FIGS. 5A through 5C illustrate where the glass (10) flowing in the downcomer feed pipe (7) ends up in the formed glass sheet for the inventions described in FIGS. 3 and 4. The glass flow to the center of the sheet (21) is virtually identical to that in the prior art. However, the flow (52) which forms the outside surface of the formed glass sheet does not flow in proximity to the front surface of the downcomer pipe (7). The two portions of the glass flow (24) which are symmetrically offset from the front surface at an angle of approximately 45 degrees and which end up forming the unusable edge section (25) at the inlet end of the sheet are substantially unaffected, as is the glass flow (26) which ends up in the unusable edge section (27).

FIG. 6 is an embodiment that shows the axis of the bowl (66) inclined at an angle such that the main process stream passes through the front of the bowl. This active flow (60) entrains the surface glass (61), overcoming the surface tension forces that would normally create a quiescent zone of glass flow located at the bowl nose (FIG. 8). A needle (13) is present to stop glass flow.

FIGS. 7A through 7D show an embodiment of the present invention where a crossways motion of the glass in the bowl (76) is facilitated by feeding the glass in the pipe coming from the stirring device to the bowl (75), into the side of the bowl (76) at an angle (74) with respect to the centerline (73) of the forming apparatus (9). This effectively changes the flow pattern (70) in the bowl such that the quiescent zone normally located at the bowl nose (81, FIG. 8) is moved to the side of the bowl (71). Referring back to FIGS. 2A-2C

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and 5A-5C, depending on the angle (74) of the flow in the bowl with respect to the centerline (73) of the forming apparatus (9), the glass from the quiescent zone (71) ends up in either the unusable portion of the edges (25), (27) or is submerged in the center of the glass sheet (21) instead of on the surface of the glass sheet (23). The glass free surface (72) in the bowl is also shown.

FIG. 8 illustrates the prior art with a bowl (6) which shows the quiescent zone (81) of glass that is located at the front of the bowl (6). This glass is kept in place by a combination of low process stream flow (80) at the front of the bowl and surface tension.

FIGS. 9A through 9C show an embodiment of the present invention where the bottom end (94) of the downcomer pipe (97) is located substantially above the glass free surface (90) in the forming apparatus inlet pipe (98). The bottom end of the downcomer pipe (97) and the forming apparatus inlet (98) also have a specific size and shape, (95) and (92), respectively. The vertical distance (93) and the size and shape (92) of the forming apparatus inlet (98) is specifically designed to minimize any zone of quiescent or vortex flow in the glass flow path (91). Thus, the molten glass (10) forms a more homogenous sheet (11). This design is determined by solution of the fluid flow equations (Navier-Stokes Equations) and by experimental tests.

FIGS. 10A through 10C show a downcomer pipe (7) submerged in the molten glass surface (100) in the forming apparatus inlet pipe (8) as known in the prior art. There is a quiescent zone (101) between the two pipes (7) and (8). The glass flow path (103) produces an annular vortex (102) of glass between the downcomer pipe (7) and the trough inlet pipe (8). The vortex exchanges little material with the main process stream except during flow transients at which time it produces defects in the glass sheet.

Reducing Degradation of Sheet Glass Forming Apparatus

Referring now to FIGS. 12 through 16, another embodiment of the present invention controls the flow distribution of glass on the forming apparatus in a manner such that the degradation of the production apparatus and the deformation of the forming trough that results from thermal creep is compensated by thermal control of the glass flow distribution.

U.S. Pat. No. 3,338,696 relies on a specifically shaped forming trough to distribute the glass in a manner to form a sheet of uniform thickness. The basic shape of this forming trough is described in detail in U.S. Pat. No. 3,338,696. The sheet glass forming process is conducted at elevated temperatures, typically between 1000° C. and 1350° C. At these temperatures, the refractory materials used for construction of the forming trough exhibit a property called thermal creep, which is deformation of the material caused by applied stress. Thus, the trough deforms under the stress caused by its own weight and the stress caused by the hydrostatic pressure of the glass in the trough.

The materials used in the construction of the other parts of the forming apparatus also degrade (warp, crack, change thermal properties, etc.) in an indeterminate way, which has an adverse effect on thickness distribution. The thickness control system of U.S. Pat. No. 3,682,609 can compensate for small thickness errors, but it can only redistribute the glass over distances on the order of 5-10 cm. To significantly effect thickness distribution over the entire width of the glass sheet, the flow of the molten glass over the weirs must be controlled.

This embodiment of the invention solves this problem by introducing a precise thermal control system to redistribute the flow of molten glass at the weirs, which is the most

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critical area of the forming process. This thermal control effectively counteracts the degradation of the sheet forming apparatus which inevitably occurs during a production campaign.

FIG. 12A shows the side view of the forming trough (9) with arrows showing the flow of molten glass (10) through the forming trough (9) to the side weirs (115). FIG. 12B shows a section through the center of the forming trough (9) which shows the different zones for the control of molten glass (10) as it flows through the forming apparatus. Zone (121) is the flow from the inlet end of the trough to the far end, zone (122) is the flow over the weirs, zone (123) is the flow down the outside of the forming trough, and zone (124) is the molten glass (11) being pulled off the root (116) and cooling into a solid sheet (12). The effect on the solid glass sheet (12) thickness caused by heating or cooling the molten glass (10) as it passes through each zone is different. Adding energy to (raising the temperature of) or removing energy from the molten glass (10) as it flows from the inlet end to the far end of the forming trough (9) in zone (121) produces concave or convex sheet thickness profiles respectively. The period of the thickness profile changes effected in zone (121) is on the order of the length of the trough.

Changes to the energy flux to the molten glass (10) as it flows over the weirs (115) in zone (122) has a powerful effect on the resultant solid glass sheet thickness distribution. Localized cooling of the glass in zone (122) effectively produces a dam, which has a large effect on glass flow. This is an extremely sensitive zone, and any control strategy other than isothermal must be carefully designed. Zone (123) is important to return the glass to a uniform temperature distribution, substantially linear in the longitudinal direction, in order that the drawing process at the root (116) is consistent. Differential cooling in zone (124) is the object of U.S. Pat. No. 3,682,609 and is effective in making small thickness distribution changes. Cooling at given longitudinal location affects the thickness at that location in one direction and conversely to the glass on each side of the location. The effect is longitudinal redistribution of the glass over a distance on the order of centimeters.

FIGS. 13A and 13B show an embodiment of this invention whereby the top and sides of the muffle (132) are shaped more closely to the outside surface of the molten glass (10) that is flowing in and on the forming trough (9). The muffle (132) is heated by heating elements in heating chamber (131). The primary heat transfer medium in the muffle chamber (113) is radiation. By designing the muffle (132) to conform closely to the outside shape of the molten glass (10), energy may be directed to targeted areas of the molten glass (10), thereby effecting greater control of temperature distribution. The heating elements in the heating chamber (131) have adequate power to balance the energy flux to the forming trough (9) and thus create suitable temperature conditions.

FIGS. 14A and 14B show an embodiment of this invention which effects localized cooling of the molten glass (10) as it passes over the weirs (115) in zone (122). The muffle (132) configuration of FIGS. 13A and 13B is used. Air cooling tubes (142), similar in function to those air cooling tubes (141), which are described in U.S. Pat. No. 3,682,609, are directed at the heating chamber side of the muffle (143) just above the molten glass (10) flowing over the weirs (115). Localized cooling of the glass in this location effectively produces a localized dam, which has a significant effect on the thickness distribution of the solid glass sheet.

FIGS. 15A and 15B show an embodiment of this invention whereby the multi-chamber muffle (156) is designed

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with separate heating chambers (151-155) to control the temperature of the molten glass (10) as it passes through the various individual zones of the forming process. These zones (121-124) are described in FIGS. 12A and 12B. The multi-chamber muffle (156) has five heating chambers (151-155). Heating chamber (153), located over the top of the forming trough (9), effects the flow of glass from the inlet end to the far end of the forming trough (9), (zone (121)). The heating chambers (152) and (154) over the top of the weirs (115) effect the flow over the weirs (115) (zone (122)), and the heating chambers (151) and (155) on each side of the trough (9) are used to balance the temperature longitudinally (zone (123)). All the heating chambers (151-155) have heating elements with adequate power to balance the energy flux to the forming trough (9) and thus create suitable temperature conditions.

FIGS. 16A and 16B show an embodiment of this invention which affects localized cooling to the molten glass (10) as it passes over the weirs (115). This is zone (122) shown in FIG. 12B. The multi-chamber muffle (156) configuration of FIGS. 15A and 15B is used. Specially designed radiant coolers (161), installed in heating chambers (152) and (154), have the ability to selectively cool the heating chamber side of the muffle surface (162) opposite the weirs (115). The radiant cooler has multiple adjustments (164) such that the temperature of its bottom surface can be varied in the longitudinal direction. The distribution of the heat transfer between the radiant cooler (161) and the muffle surface (162) is a function of the distance (163). By varying the distance (163) between the cooling device (161) and the muffle surface (162), the cooling effect may be attenuated to adjust sensitivity. Although it is not illustrated, the cooling devices (161) are replaceable during operation. The radiant coolers (161) could alternately be inserted from the side instead of the top with a suitable change in the design of the heating chambers (152), (153) and (154).

In an alternative embodiment, the air cooling tubes (142) of FIG. 14A and 14B could be used with the muffle (156) design of FIGS. 15A and 15B, and the radiant coolers (161) of FIGS. 16A and 16B could be used with the muffle (132) configuration of FIGS. 13A and 13B.

Reducing Thickness Variations in the Glass Sheet

Referring to FIGS. 17 through 20, another embodiment of the present invention supports and stresses the forming apparatus in a manner such that the deformation that results from thermal creep has a minimum effect on the thickness variation of the glass sheet. This embodiment introduces a counteracting force to these stresses on the trough in a manner such that the thermal creep which inevitably occurs has a minimum impact on the glass flow characteristics of the forming trough. The invention is designed such that this counteracting force is maintained through an extended period of the production campaign. Thus, sheet glass may be manufactured for a longer time with the same forming trough.

The refractory materials from which the forming trough and its support structure are made have high strength in compression and low strength in tension. Like most structural materials, they also change shape when stressed at high temperature. This embodiment was developed due to the material characteristics and how these characteristics affect the manufacturing process.

There are two fundamental concepts in this embodiment of the invention. First, applying a force and/or moment to the ends of the trough counteracts stress caused by the forces of gravity, thus minimizing the effect on molten glass flow caused by thermal creep. Second, the invention uses com-

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pression members shaped such that thermal creep, to which the compression members are also subject, does not substantially alter the application of said force and/or moment.

FIGS. 17A and 17B illustrate the typical effects of thermal creep on the shape of the trough. FIG. 17A shows that the forming trough (9) sags in the middle such that the top of the weirs (115), and the root (116) are now curved (171) and the trough bottom (117) has a change in curvature (171). This curvature (171) causes the molten glass (10) to no longer flow with constant thickness (172) over the weirs (115). This curvature (171) allows more glass to flow over the middle of the weirs resulting in an uneven sheet thickness distribution. FIG. 17B shows how the hydrostatic force (174) from the molten glass (10) in the forming trough (9) forces the weirs (115) to move apart at the top. This allows more glass to flow to the middle of the forming trough (9) making the thickness in the middle even greater.

FIGS. 18A through 18D show a sheet glass forming apparatus (180) as known in the prior art. The forming trough (9) is supported by an inlet end supporting block (181) and a far end supporting block (182). The forming trough (9) is the equivalent of a beam, which is subject to a bending stress from its own weight, from the weight of the glass in and on the trough, and from drawing forces. Because of the low tensile strength of the trough material, a compressive force (183) is applied to the lower half of the forming trough (9) to force the material at the root (116) of the forming trough (9) into compression. Typically the inlet end support block (181) is restrained in the longitudinal (horizontal) direction and the compression force (183) is applied to the far end support block (182). The prior art considers only preventing tension at the root (116) of the forming trough (9), and then only the stress at start-up. Little consideration is made for the effects on stress of the thermal creep of the forming trough (9) and its support blocks (181) and (182).

FIGS. 19A through 19D show an embodiment of a sheet glass forming apparatus (190) that has shaped end support blocks (191) and (192). The inlet end shaped support block (191) is restrained in the longitudinal direction. A compression force (193) is applied to the far end shaped support block (192). The shape of the support block is designed in a manner to produce a force distribution in the forming trough (9) to substantially counteract the effect of the weight of the forming trough (9) and the molten glass (10). The applied force (193) is such that all material in the forming trough (9) is under substantially equal compression stress in the longitudinal direction. This stress causes the thermal creep to occur primarily in the longitudinal direction with little of the sagging shown in FIG. 17A. The forming trough (9) gets shorter due to the equal compressive stress in the longitudinal direction. The shaped support blocks are also subject to thermal creep. The cross section of the shaped support block is the same over substantially its entire length with equal compressive stress across its section. Thus as the shaped support block deforms from thermal creep, it continues to apply substantially the same force distribution to the forming trough (9).

FIGS. 20A through 20D show an embodiment of a sheet glass forming apparatus (200) that has four shaped end support blocks (201), (202), (204), and (205). The inlet end has three shaped support blocks (201), (204), and (205), all of which have longitudinal compression forces (206), (207), and (208) applied. A compression force (203) is applied to the far end shaped support block (202). The shape and loading of the support blocks (202) and (203) are designed to the same criteria as support blocks (191) and (192) in

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FIGS. 19A–19D. The two upper shaped support blocks (204) and (205) are attached to the inlet end of the weirs and are angled such that they exert an additional force on the weirs to counteract the affect of the hydrostatic forces which tend to spread the weirs apart. Although the blocks (204) and (205) are shown with an inward angle in the figures, they also could be angled outward without deviating from the spirit of the invention.

In a preferred embodiment, short (10–25% of length) transition zones (not shown) are at the trough ends of the shaped support blocks. In these transition zones, the cross-section of the shaped support block will change from that of the shaped support block to a shape that will suitably apply the design load to the trough block.

Effects of Surface Tension on the Sheet

In an alternative embodiment of the invention, the width and the angle of the inverted slope of the forming wedge may be changed to alter the effect of surface tension and body forces on the narrowing of the sheet. In addition, the width and the inverted slope angle may be increased to make the structure stiffer and thus more resistant to thermal creep.

FIGS. 21A through 21G show the prior art shape of the forming trough. The cross-section of the wedge shaped portion, FIGS. 21C through 21G, is uniform over the entire useable length of the trough. The width of the trough (211) and the angle of the inverted slope (210) are identical at each section. As the molten glass (10) flows down the vertical portion (211) of the forming wedge (9), the surface tension and body forces have a minimal effect on the sheet width (212), whereas, when the molten glass (10) flows vertically down the inverted slope portion (210) of the forming wedge, the surface tension and body forces act to make the sheet narrower (213).

FIGS. 22A through 22G show an identical width of the trough (211) over its entire length, whereas the angle of the inverted slope (210) is the same in the center of the trough (FIGS. 21D–21F) and the angle of the inverted slope (220) at each end is reduced. This reduced inverted slope (220) has a counterbalancing effect on the surface tension and body force stresses and thus reduces the narrowing of the sheet (223).

FIGS. 23A through 23G show the width of the trough (211) and the angle of the inverted slope (210) being the same in the center of the trough (FIGS. 21D through 21F and FIGS. 22D through 22F), whereas, the width of the trough (231) and the angle of the inverted slope (230) at each end are reduced. This reduced width (231) and inverted slope (230) have a counterbalancing effect on the surface tension and body force stresses over the effect of FIGS. 22A through 22G and thus further reduces the narrowing of the sheet (233).

FIGS. 24A through 24G show another embodiment of this invention, wherein the width of the trough (211) and (231) and the angle of the inverted slope (210) and (230) are the same as in the embodiment of FIGS. 23A through 23G except that the angle of the inverted slope (240) at the center of the trough, FIG. 24E is substantially greater than the other inverted slopes (210) and (230). This greater angle increases the section modulus of the structure making it stiffer and thus less prone to thermal creep. Keeping the configuration of the ends the same as FIGS. 23A through 23G has substantially the same effect on the surface tension and body force stresses as FIGS. 23A through 23G and thus has little effect on the narrowing of the sheet (243).

Producing a Flat Sheet

U.S. Pat. No. 3,338,696 considers only the glass flow in the forming trough and assumes that the drawn glass from

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the bottom of the forming trough will be of uniform thickness and flatness because of the uniform thickness of the flow of glass to the critical point of solidification. In practice, glass must be preferentially cooled across its width to create forming stresses during solidification that create a flat sheet. The present invention alters the forming stresses and cooling distribution such that the formed sheet is inherently flat.

FIGS. 25A through 25D show an embodiment of this invention where the shape of the bottom of the forming wedge (116) is not straight but is formed convex upward (250). This causes the glass that is drawn from the center of the forming wedge (251) to cool faster than the glass drawn from each edge (252) of the forming wedge. The strategy is to impose stresses on the partially solidified glass (251) in the center of the sheet to cause the sheet to be flatter, having less warp.

FIGS. 26A through 26D show another embodiment of this invention where the shape of the bottom of the forming wedge (116) is not straight but is formed convex downward (260). This causes the glass that is drawn from the center of the forming wedge (261) to cool slower than that drawn from each edge (262) of the forming wedge. The strategy is to hold the more solidified edges (262) apart, primarily with the edge rollers (110), such that stresses caused by the shrinkage of the partially solidified glass (261) in the center of the sheet cause the sheet to be flatter, having less warp.

FIGS. 27A through 27D show an embodiment of this invention where the shape of the bottom of the forming wedge (116) is not straight but has complex shape across its width (270). This causes the glass that is drawn from the forming wedge (9) to have an equivalent cooling profile. The cooling strategy from this configuration would be a combination of that shown in FIGS. 25A through 25D and 26A through 26D.

Reducing Air Leakage

U.S. Pat. No. 3,338,696 relies primarily on careful design and matching of materials to prevent any material cracks and openings. These cracks and openings are the sources of air leakage, for both initial operation and for operation during the course of a manufacturing campaign. This embodiment of the invention provides individual pressure balancing technology such that even if a leakage path exists at start-up or develops during operation, a minimum quantity of air will flow through the leakage paths.

The glass sheet is formed by drawing the glass from the bottom of the overflow forming trough. The molten glass is cooled and is solidified in a carefully controlled manner. The most desirable cooling phenomena is radiation, which cools the glass substantially evenly through its entire thickness. Convective cooling, which cools only the glass surface, is also a factor. The convective cooling must be minimized as it has a destabilizing effect on the drawing process. The observed phenomena is a cyclic variation in sheet thickness as it is drawn. This is termed “pumping” and is a phenomena noted in all glass drawing processes.

The operating temperature of the forming zone of “The Overflow Process” is typically 1250° C. and is at the top of an open bottom chamber, typically 3 meters high, containing an atmosphere of hot air. Because of the approximately 3 meter column of high temperature air, the atmosphere in the zone where the sheet is formed has a pressure higher than the pressure outside of the forming apparatus. Therefore, any crack or opening creates an airflow path whereby air flows into the open bottom of the chamber, up the chamber and out the cracks or openings. This leakage substantially increases the convective cooling in the forming zone and subsequently produces a cyclic variation in the sheet thickness.

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For air to flow through an opening there must be a difference in pressure from one side of the opening to the other. This invention involves adjusting the internal pressure in each of the major components of the forming apparatus such that the pressure difference across any leakage path to the forming zone is essentially zero. Therefore, if an opening either exists or develops, no air leakage will occur as there is no differential pressure to force airflow.

The air pressure in the internal chambers of the forming system is substantially higher than the ambient pressure in the factory. This is because of the low density of the heated air contained in the forming system. This elevated pressure forces the internal air to leak through any openings or cracks in the membranes which separate the forming zones from the heating and cooling zones. The leakage can be minimized by equalizing the air pressure on each side of any leakage path.

Referring now to FIGS. 28A through 32B, FIGS. 28A and 28B show cooling of the glass as it transitions from the molten state to the solid state. This process must be carefully controlled. This cooling process starts on the lower part of the forming apparatus (9) just above the root (116), in the muffle zone (280), continues as the molten glass sheet (11) passes through the muffle door zone (114), and is substantially solidified by the time it leaves the transition zone (281). The controlled cooling process continues in the annealer and pulling machine zone (282) to relieve internal stress in the solidified glass sheet (12).

Four embodiments for controlling forming chamber pressure differentials are shown in FIGS. 29A through 32B. These are a) adding flow to pressurize, b) restricting outflow, c) flowing to a vacuum, and d) encasement by a pressurizing chamber, respectively. Any of these control methods may be used to control the pressure in either the muffle zone (280), the muffle door zone (114), the transition zone (281), or the annealing and pulling machine zone (282) depending on unique design requirements. The critically important objective, however, is to equalize the pressure on each side of the membrane separating either the factory atmosphere or a heating zone or a cooling zone from the forming chamber. This invention also applies to implementations of "The Overflow Process" where the gas in the forming chamber is a gas other than air, i.e. nitrogen, etc.

More specifically, FIGS. 29A and 29B show an embodiment of the muffle zone (280) which shows air (290), which is preferably preheated, introduced into the muffle heating chamber (131) to make the pressure in the heating chamber (131) equal to that in the adjacent forming chamber (113). The wall (132) separating the two chambers in the muffle is normally constructed of many pieces and is therefore susceptible to random leaks. Equalizing the pressure between the two chambers minimizes the leakage flow.

FIGS. 30A and 30B show an embodiment of the muffle door zone (114), which includes an exit restriction (300) to the flow of air exiting each muffle door (301) to factory ambient pressure. The size of this restriction is varied to regulate the pressure inside the muffle door (302) equal to that in the pressure in the adjacent forming chamber (303). The flow of air into the muffle doors (301) through the cooling tubes (141) would normally be adequate to overcome any leakage paths and thus raise the muffle door internal pressure (302) to that of the adjacent forming chamber pressure (303).

FIGS. 31A and 31B show an embodiment of the transition zone (281), which has the cooling air at elevated pressure (310) entering the cooling chamber (311) and exiting (312) each of the transition coolers (313) into a regulated vacuum

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source (314). The large volume of air required for cooling in the transition zone would normally raise the pressure in the transition cooling chamber (311) above that of the adjacent forming chamber (315). A vacuum source (314) is therefore required to lower the pressure and is adjusted to equalize the pressure in the transition cooling chamber (311) to the pressure in the adjacent forming chamber (315).

FIGS. 32A and 32B show an embodiment of the annealer and pulling machine zone (282), which includes a pair of pressure balancing chambers (320) on each end of the annealer and pulling machine (282). The pressure in the balancing chamber (321) is adjusted to be equal to the pressure in the annealing chamber (322). A chamber at each end was chosen because the bearings and adjustment mechanisms for the pulling rollers (111) are on the ends. Alternate configurations would be one single pressure balancing chamber (320) encasing the entire annealer and pulling machine (282) or a multitude of individual pressure balancing chambers (320) as would be required by particular design considerations.

Accordingly, it is to be understood that the embodiments of the invention herein described are merely illustrative of the application of the principles of the invention. Reference herein to details of the illustrated embodiments is not intended to limit the scope of the claims, which themselves recite those features regarded as essential to the invention.

What is claimed is:

1. An improved apparatus for forming sheet glass, wherein the apparatus includes an inflow pipe for delivering molten glass, a trough for receiving molten glass that has sides attached to a wedged shaped sheet forming structure that has downwardly sloping sides converging at the bottom of the wedge such that a glass sheet is formed when molten glass flows over the sides of the trough, down the downwardly sloping sides of the wedged shaped sheet forming structure and meets at the bottom of wedge, and wherein the improvement comprises a flow distribution device located under a surface of the glass at an inlet to the trough.

2. The improved apparatus of claim 1, wherein the flow distribution device redistributes a surface flow of the molten glass.

3. The improved apparatus of claim 2, wherein the apparatus reduces a plurality of inhomogeneities in the glass forming the usable portion of the formed sheet.

4. The improved apparatus of claim 1, wherein the improvement further comprises a bowl connected to the inflow pipe at an end opposite the trough via a downcomer pipe, wherein an axis of the bowl is inclined such that a main stream of the molten glass passes through a front of the bowl.

5. The improved apparatus of claim 1, wherein the improvement further comprises a bowl connected to the inflow pipe at an end opposite the trough via a downcomer pipe, wherein the molten glass is fed into the bowl off an axis of a centerline of the trough.

6. The improved apparatus of claim 5, wherein the glass is fed into the bowl at an angle between 30 degrees and 180 degrees with respect to the axis of the centerline of the trough such that the less desirable glass is not on the surface of the sheet.

7. The improved apparatus of claim 6, wherein the glass is fed into the bowl at an angle of approximately 180 degrees such that the less desirable glass proceeds to the far end unusable edge section of the formed glass sheet.

8. The improved apparatus of claim 6, wherein the glass is fed into the bowl at an angle of approximately 45 degrees such that the less desirable glass proceeds to the near end unusable edge section of the formed glass sheet.

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9. The improved apparatus of claim 1, wherein the improvement further comprises a downcomer pipe connected to an end of the inflow pipe opposite the trough, wherein a bottom end of the downcomer pipe is located substantially above a glass free surface in the inflow pipe and the downcomer pipe and the inflow pipe have a size and shape which minimizes a zone of quiescent or vortex flow in a path of glass flow.

10. The improved apparatus of claim 1, wherein the improvement further comprises a muffle, wherein the top and sides of the muffle are shaped to an outside surface of the molten glass flowing in and on the trough.

11. The improved apparatus of claim 10, wherein the improvement further comprises at least one heating chamber located adjacent to the muffle on a side opposite the trough.

12. The improved apparatus of claim 11, wherein the improvement further comprises a plurality of air cooling tubes directed at a heating chamber side of the muffle just above the molten glass, wherein the air cooling tubes vary a temperature in a longitudinal direction.

13. The improved apparatus of claim 11, wherein the improvement further comprises a plurality of radiant coolers installed in the heating chamber just above the molten glass, wherein the radiant coolers vary a temperature in a longitudinal direction.

14. The improved apparatus of claim 10, wherein a structure of the muffle creates five heating chambers comprising:

- a) a heating chamber over a top of the trough;
- b) a heating chamber over a left side of the trough sides;
- c) a heating chamber over a right side of the trough sides;
- d) a heating chamber on a left side of the trough; and
- e) a heating chamber on a right side of the trough.

15. The improved apparatus of claim 1, wherein the improvement further comprises:

- a) at least one inlet end support block located at an inlet end of the trough, wherein the inlet end support block supports the trough; and
- b) at least one far end support block located at an opposite end of the trough as the inlet end support block, wherein the far end support block supports the trough; wherein the inlet end support block and the far end support block are shaped to distribute force in the trough to counteract the effect of the weight of the trough such that an applied force puts all the refractory that comprises the trough structure under substantially equal compression stress in a longitudinal direction; such that any deformation of the forming trough that results from thermal creep has a minimal effect on a thickness variation of the glass sheet.

16. The improved apparatus of claim 15, wherein there are three inlet end support blocks, wherein two of the inlet end support blocks are attached to an inlet end of each of the trough sides and angle to exert an additional force on the trough sides to counteract a plurality of hydrostatic forces which spread the trough sides apart.

17. The improved apparatus of claim 15, wherein the improvement further comprises:

- c) a shape of each support block such that the support block is uniformly stressed in the longitudinal direction;

wherein the thermal creep of the support block is uniform, thereby maintaining a required force distribution on the trough; and

- d) a transition zone in a support block shape of approximately 10-25% of the length of the support blocks to adapt its shape to that of the trough.

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18. The improved apparatus of claim 1, wherein the improvement further comprises a variable cross-section of the apparatus.

19. The improved apparatus of claim 18, wherein an angle of an inverted slope at each end of the trough is less than an angle of an inverted slope at a center of the trough.

20. The improved apparatus of claim 18, wherein a width of the trough at an end of the trough is less than a width of the trough at a center of the trough.

21. The improved apparatus of claim 18, wherein an angle of an inverted slope at a center of the trough is substantially greater than the angle of the inverted slopes not in the center of the trough.

22. The improved apparatus of claim 1, wherein the improvement further comprises a shape of a bottom of the wedge shaped sheet forming structure selected from the group consisting of:

- a) convex upward;
- b) convex downward; and
- c) a wave comprising both convex downward and convex upward portions;

such that a sheet formed from the apparatus is flat.

23. The improved apparatus of claim 22, wherein the shape of the bottom of the wedge shaped sheet forming structure affects a thickness distribution of the glass in the edges of the sheet.

24. The improved apparatus of claim 1, wherein an internal pressure between adjacent chambers in the apparatus during a glass cooling process are adjusted such that a pressure difference across an air leakage path to a forming zone is substantially zero, thereby eliminating air leakage.

25. The improved apparatus of claim 24, wherein the chambers comprise:

- a) a muffle zone enclosing the forming trough;
- b) a muffle door zone, located at a bottom of the wedge of the trough;
- c) a transition zone, which transitions the molten glass between the muffle door zone and an annealer and pulling machine zone; and
- d) the annealer and pulling machine zone.

26. The improved apparatus of claim 24 wherein the adjustment is accomplished by adding air flow to one of the adjacent chambers.

27. The improved apparatus of claim 24, wherein the adjustment is accomplished by restricting an outflow of air from one of the adjacent chambers to factory ambient pressure.

28. The improved apparatus of claim 24, further comprising a vacuum source to lower a pressure in one of the adjacent chambers.

29. The improved apparatus of claim 24, further comprising at least one supplementary pressure chamber, wherein the adjustment is accomplished by encasing one chamber in the pressure chamber.

30. The improved apparatus of claim 29, wherein there are at least two supplementary pressure chambers.

31. An improved apparatus for forming sheet glass, wherein the apparatus includes an inflow pipe for delivering molten glass, a trough for receiving molten glass that has sides attached to a wedged shaped sheet forming structure that has downwardly sloping sides converging at the bottom of the wedge such that a glass sheet is formed when molten glass flows over the sides of the trough, down the downwardly sloping sides of the wedged shaped sheet forming structure and meets at the bottom of wedge, and wherein the improvement comprises a surface flow distribution device

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located at an inlet to the trough, wherein the flow distribution device redistributes a surface flow of the molten glass.

32. The improved apparatus of claim 31, wherein the apparatus reduces a plurality of inhomogeneities in the glass forming the usable portion of the formed sheet.

33. An improved apparatus for forming sheet glass, wherein the apparatus includes an inflow pipe for delivering molten glass, a trough for receiving molten glass that has sides attached to a wedged shaped sheet forming structure that has downwardly sloping sides converging at the bottom of the wedge such that a glass sheet is formed when molten glass flows over the sides of the trough, down the downwardly sloping sides of the wedged shaped sheet forming structure and meets at the bottom of wedge, and wherein the improvement comprises a bowl connected to the inflow pipe at an end opposite the trough via a downcomer pipe, wherein an axis of the bowl is inclined such that a main stream of the molten glass passes through a front of the bowl.

34. An improved apparatus for forming sheet glass, wherein the apparatus includes an inflow pipe for delivering molten glass, a trough for receiving molten glass that has sides attached to a wedged shaped sheet forming structure that has downwardly sloping sides converging at the bottom of the wedge such that a glass sheet is formed when molten glass flows over the sides of the trough, down the downwardly sloping sides of the wedged shaped sheet forming structure and meets at the bottom of wedge, and wherein the improvement comprises a bowl connected to the inflow pipe at an end opposite the trough via a downcomer pipe, wherein the molten glass is fed into the bowl off an axis of a centerline of the trough.

35. The improved apparatus of claim 34, wherein the glass is fed into the bowl at an angle between 30 degrees and 180 degrees with respect to the axis of the centerline of the trough such that the less desirable glass is not on the surface of the sheet.

36. The improved apparatus of claim 35, wherein the glass is fed into the bowl at an angle of approximately 180 degrees such that the less desirable glass proceeds to the far end unusable edge section of the formed glass sheet.

37. The improved apparatus of claim 35, wherein the glass is fed into the bowl at an angle of approximately 45 degrees such that the less desirable glass proceeds to the near end unusable edge section of the formed glass sheet.

38. An improved apparatus for forming sheet glass, wherein the apparatus includes an inflow pipe for delivering molten glass, a trough for receiving molten glass that has sides attached to a wedged shaped sheet forming structure that has downwardly sloping sides converging at the bottom of the wedge such that a glass sheet is formed when molten glass flows over the sides of the trough, down the downwardly sloping sides of the wedged shaped sheet forming structure and meets at the bottom of wedge, and wherein the improvement comprises a downcomer pipe connected to an end of the inflow pipe opposite the trough, wherein a bottom end of the downcomer pipe is located substantially above a glass free surface in the inflow pipe and the downcomer pipe and the inflow pipe have a size and shape which minimizes a zone of quiescent or vortex flow in a path of glass flow.

39. An improved apparatus for forming sheet glass, wherein the apparatus includes a trough for receiving molten glass that has sides attached to a wedged shaped sheet forming structure that has downwardly sloping sides converging at the bottom of the wedge such that a glass sheet is formed when molten glass flows over the sides of the trough, down the downwardly sloping sides of the wedged shaped sheet forming structure and meets at the bottom of wedge, and wherein the improvement comprises five heating chambers.

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40. The improved apparatus of claim 39, wherein the five heating chambers comprise:

- a) a heating chamber over a top of the trough;
- b) a heating chamber over a left side of the trough sides;
- c) a heating chamber over a right side of the trough sides;
- d) a heating chamber on a left side of the trough; and
- e) a heating chamber on a right side of the trough.

41. An improved apparatus for forming sheet glass, wherein the apparatus includes a trough for receiving molten glass that has sides attached to a wedged shaped sheet forming structure that has downwardly sloping sides converging at the bottom of the wedge such that a glass sheet is formed when molten glass flows over the sides of the trough, down the downwardly sloping sides of the wedged shaped sheet forming structure and meets at the bottom of wedge, and wherein the improvement comprises:

- a) at least one inlet end support block located at an inlet end of the trough, wherein the inlet end support block supports the trough; and
- b) at least one far end support block located at an opposite end of the trough as the inlet end support block, wherein the far end support block supports the trough; wherein the inlet end support block and the far end support block are shaped to distribute force in the trough to counteract the effect of the weight of the trough such that an applied force puts all the refractory that comprises the trough structure under substantially equal compression stress in a longitudinal direction; such that any deformation of the forming trough that results from thermal creep has a minimal effect on a thickness variation of the glass sheet.

42. The improved apparatus of claim 41, where there are three inlet end support blocks, wherein two of the inlet end support blocks are attached to an inlet end of each of the trough sides and angle to exert an additional force on the trough sides to counteract a plurality of hydrostatic forces which spread the trough sides apart.

43. The improved apparatus of claim 41, wherein the improvement further comprises:

- c) a shape of each support block such that the support block is uniformly stressed in the longitudinal direction;
- wherein the thermal creep of the support block is uniform, thereby maintaining a required force distribution on the trough; and
- d) a transition zone in a support block shape of approximately 10-25% of the length of the support blocks to adapt its shape to that of the trough.

44. The improved apparatus of claim 41, wherein the improvement further comprises a variable cross-section of the apparatus.

45. The improved apparatus of claim 44, wherein an angle of an inverted slope at each end of the trough is less than an angle of an inverted slope at a center of the trough.

46. The improved apparatus of claim 44, wherein a width of the trough at an end of the trough is less than a width of the trough at a center of the trough.

47. The improved apparatus of claim 44, wherein an angle of an inverted slope at a center of the trough is substantially greater than the angle of the inverted slopes not in the center of the trough.

48. The improved apparatus of claim 41, wherein the improvement further comprises a shape of a bottom of the wedge shaped sheet forming structure selected from the group consisting of:

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- a) convex upward;
- b) convex downward; and
- c) a wave comprising both convex downward and convex upward portions;

such that a sheet formed from the apparatus is flat.

49. The improved apparatus of claim 48, wherein the shape of the bottom of the wedge shaped sheet forming structure affects a thickness distribution of the glass in the edges of the sheet.

50. An improved apparatus for forming sheet glass, wherein the apparatus includes a trough for receiving molten glass that has sides attached to a wedged shaped sheet forming structure that has downwardly sloping sides converging at the bottom of the wedge such that a glass sheet is formed when molten glass flows over the sides of the trough, down the downwardly sloping sides of the wedged shaped sheet forming structure and meets at the bottom of wedge, and wherein the improvement comprises a shape of a bottom of the wedge shaped sheet forming structure selected from the group consisting of:

- a) convex downward; and
- b) a wave comprising both convex downward and convex upward portions;

such that a sheet formed from the apparatus is flat.

51. The improved apparatus of claim 50, wherein the shape of the bottom of the wedge shaped sheet forming structure affects a thickness distribution of the glass in the edges of the sheet.

52. A method for reducing air leakage when forming sheet glass using an apparatus that includes a trough for receiving molten glass that has sides attached to a wedged shaped sheet forming structure that has downwardly sloping sides converging at the bottom of the wedge such that a glass sheet is formed when molten glass flows over the sides of the trough, down the downwardly sloping sides of the wedged shaped sheet forming structure and meets at the bottom of wedge, wherein the method comprises the step of:

- a) adjusting an internal pressure between adjacent chambers in the apparatus during a glass cooling process such that a pressure difference across an air leakage path to a forming zone is substantially zero, thereby eliminating air leakage.

53. The method of claim 52, wherein the chambers comprise:

- a) a muffle zone enclosing the forming trough;
- b) a muffle door zone, located at a bottom of the wedge of the trough;
- c) a transition zone, which transitions the molten glass between the muffle door zone and an annealer and pulling machine zone; and
- d) the annealer and pulling machine zone.

54. The method of claim 52, wherein step (a) is accomplished by adding air flow to one of the adjacent chambers.

55. The method of claim 52, wherein step (a) is accomplished by restricting an outflow of air from one of the adjacent chambers to factory ambient pressure.

56. The method of claim 52, wherein step (a) is accomplished by providing a vacuum source to lower a pressure in one of the adjacent chambers.

57. The method of claim 52, wherein step (a) is accomplished by encasing one chamber in at least one supplementary pressure chamber.

58. The method of claim 52, wherein there are at least two supplementary pressure chambers.

59. The method of claim 52, wherein the apparatus further comprises a flow distribution device located under a surface of the glass.

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60. The method of claim 59, wherein the apparatus reduces a plurality of inhomogeneities in the glass forming the usable portion of the formed sheet.

61. The method of claim 52, wherein the apparatus further comprises:

- a) an inflow pipe for delivering molten glass to the trough; and

- b) a surface flow distribution device located at an inlet to the trough, wherein the flow distribution device redistributes a surface flow of the molten glass.

62. The method of claim 52, wherein the apparatus further comprises a bowl connected to the inflow pipe at an end opposite the trough via a downcomer pipe, wherein an axis of the bowl is inclined such that a main stream of the molten glass passes through a front of the bowl.

63. The method of claim 52, wherein the apparatus further comprises a bowl connected to the inflow pipe at an end opposite the trough via a downcomer pipe, wherein the molten glass is fed into the bowl off an axis of a centerline of the bowl.

64. The method of claim 63, wherein the glass is fed into the bowl at an angle between 30 degrees and 180 degrees with respect to the axis of the centerline of the trough such that the less desirable glass is not on the surface of the sheet.

65. The method of claim 64, wherein the glass is fed into the bowl at an angle of approximately 180 degrees such that the less desirable glass proceeds to the far end unusable edge section of the formed glass sheet.

66. The method of claim 64, wherein the glass is fed into the bowl at an angle of approximately 45 degrees such that the less desirable glass proceeds to the near end unusable edge section of the formed glass sheet.

67. The method of claim 52, wherein the apparatus further comprises a downcomer pipe connected to an end of the inflow pipe opposite the trough, wherein a bottom end of the downcomer pipe is located substantially above a glass free surface in the inflow pipe and the downcomer pipe and the inflow pipe have a size and shape which minimizes a zone of quiescent or vortex flow in a path of glass flow.

68. The method of claim 52, wherein the apparatus further comprises a muffle, wherein the top and sides of the muffle are shaped to an outside surface of the molten glass flowing in and on the trough.

69. The method of claim 68, wherein the apparatus further comprises at least one heating chamber, wherein the heating chamber is located adjacent to the muffle on a side opposite the trough.

70. The method of claim 69, wherein the apparatus further comprises a plurality of air cooling tubes directed at a heating chamber side of the muffle just above the molten glass, wherein the air cooling tubes vary a temperature in a longitudinal direction.

71. The method of claim 69, wherein the apparatus further comprises a plurality of radiant coolers installed in the heating chamber just above the molten glass, wherein the radiant coolers vary a temperature in a longitudinal direction.

72. The method of claim 69, wherein a structure of the muffle creates five heating chambers comprising:

- a) a heating chamber over a top of the trough;
- b) a heating chamber over a left side of the trough sides;
- c) a heating chamber over a right side of the trough sides;
- d) a heating chamber on a left side of the trough; and
- e) a heating chamber on a right side of the trough.

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73. The method of claim 52, wherein the apparatus further comprises:

- a) at least one inlet end support block located at an inlet end of the trough, wherein the inlet end support block supports the trough; and
- b) at least one far end support block located at an opposite end of the trough as the inlet end support block, wherein the far end support block supports the trough; wherein the inlet end support block and the far end support block are shaped to distribute force in the trough to counteract the effect of the weight of the trough such an applied force puts all the refractory that comprises the trough structure under substantially equal compression stress in a longitudinal direction; such that any deformation of the forming trough that results from thermal creep has a minimal effect on a thickness variation of the glass sheet.

74. The method of claim 73, wherein there are three inlet end support blocks, wherein two of the inlet end support blocks are attached to an inlet end of each of the trough sides and angle to exert an additional force on the trough sides to counteract a plurality of hydrostatic forces which spread the trough sides apart.

75. The method of claim 73, wherein the apparatus further comprises:

- c) a shape of each support block such that the support block is uniformly stressed in the longitudinal direction; wherein the thermal creep of the support block is uniform, thereby maintaining a required force distribution on the trough; and

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- d) a transition zone in a support block shape of approximately 10–25% of the length of the support blocks to adapt its shape to that of the trough.

76. The method of claim 52, wherein the apparatus further comprises a variable cross-section of the apparatus.

77. The method of claim 76, wherein an angle of an inverted slope at each end of the trough is less than an angle of an inverted slope at a center of the trough.

78. The method of claim 76, wherein a width of the trough at an end of the trough is less than a width of the trough at a center of the trough.

79. The method of claim 76, wherein an angle of an inverted sloped at a center of the trough is substantially greater than the angle of the inverted slopes not in the center of the trough.

80. The method of claim 52, wherein the apparatus further comprises a shape of a bottom of the wedge shaped sheet forming structure selected from the group consisting of:

- a) convex upward;
- b) convex downward; and
- c) a wave comprising both convex downward and convex upward portions;

such that a sheet formed from the apparatus is flat.

81. The method of claim 80, wherein the shape of the bottom of the wedge shaped sheet forming structure affects a thickness distribution of the glass in the edges of the sheet.

* * * * *

EXHIBIT A



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(12) **United States Patent**
Pitbladdo

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(54) **SHEET GLASS FORMING APPARATUS**

1,673,907 A 6/1928 Femgren

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(Continued)

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FOREIGN PATENT DOCUMENTS

DE 1596484 7/1967

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(Continued)

OTHER PUBLICATIONS

This patent is subject to a terminal disclaimer.

Varshneya, Arun, "Fundamentals of Inorganic Glasses", Academic Press, Inc., 1994, pp. 534-540.

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Primary Examiner—Sean Vincent

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(74) Attorney, Agent, or Firm—Brown & Michaels, PC

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(57) **ABSTRACT**

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(52) U.S. Cl. 65/53; 65/121; 65/195

(58) Field of Classification Search 65/53, 65/121, 195

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,565,319 A * 12/1925 Fowle 65/53

31 Claims, 32 Drawing Sheets

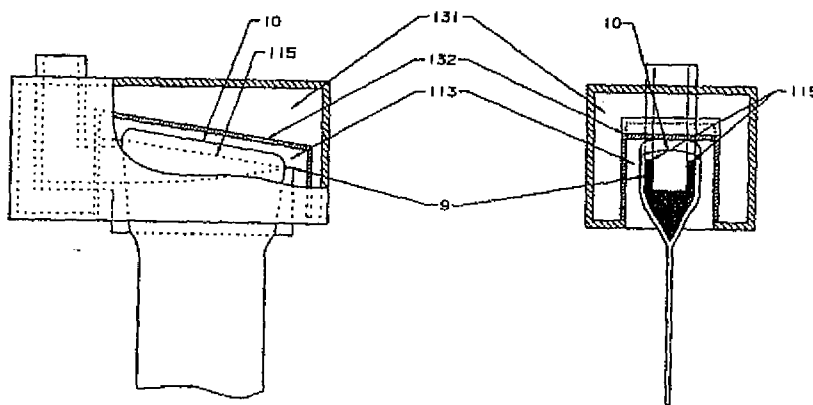


EXHIBIT B

US 7,155,935 B2

Page 2

U.S. PATENT DOCUMENTS

1,697,227 A	1/1929	Danner	
1,731,260 A	10/1929	Nobbe	
1,759,229 A	5/1930	Drake	
1,829,639 A	10/1931	Ferngren	
1,829,641 A	10/1931	Ferngren	
1,841,579 A	1/1932	Fraser	
1,891,370 A	12/1932	Danner	
3,149,949 A	9/1964	Dockerty et al.	65/53
3,338,696 A	8/1967	Dockerty	65/145
3,433,613 A	3/1969	Dockerty	65/145
3,437,470 A	4/1969	Overman	65/195
3,451,798 A	6/1969	Simon	65/199
3,506,429 A	4/1970	Overman	65/203
3,519,411 A	7/1970	Cortright et al.	65/90
3,589,887 A	6/1971	Ward	65/195
3,607,182 A	9/1971	Leibowitz	65/53
3,682,609 A	8/1972	Dockerty	65/83
3,723,082 A	3/1973	Knowles et al.	65/84
4,214,886 A	7/1980	Shay et al.	62/121
4,416,678 A	11/1983	Boltger	65/2
5,374,595 A	12/1994	Dumbaugh, Jr. et al.	501/66
6,319,867 B1	11/2001	Chacon et al.	501/66
6,889,526 B1*	5/2005	Pitbladdo	65/53
6,895,782 B1*	5/2005	Pitbladdo	65/53
6,974,786 B1	12/2005	Helfinstine et al.	501/106
6,990,834 B1*	1/2006	Pitbladdo	65/29.21
2003/0029199 A1	2/2003	Pitbladdo	65/195
2003/0110804 A1	6/2003	Fenn et al.	65/90
2003/0192349 A1	10/2003	Meda et al.	65/53

FOREIGN PATENT DOCUMENTS

DE	1596402	12/1967
DE	1596403	12/1967
DE	21 58 253	11/1971

DE	3113505	1/1983
DE	31 11484 A1	2/1983
DE	33 16795	11/1983
DE	31 11484 C2	12/1983
DE	33 14540	12/1983
DE	3329843	5/1984
DE	3507852	8/1985
DE	3518137	1/1986
DE	43 36 046	10/1993
DE	43 26 143	12/1993
DE	196 44 673	4/1998
DE	198 09 878	9/1999
DE	198 40 113	3/2000
DE	19964043	7/2001
DE	100 21 013	11/2001
DE	100 28 741	12/2001
FR	1549081	12/1967
FR	1549915	1/1968
GB	982153	2/1965
JP	09110443	4/1997
JP	10291827	11/1998
JP	11-246230	9/1999
JP	2001-80922	9/1999

OTHER PUBLICATIONS

Snyder, R.D./Byars, E.F., "Engineering Mechanics", McGraw-Hill Book Company, 1973, pp. 349-350.

Kingery, W.D.; Bowen, H.K.; Uhlmann, D.R., "Introduction to Ceramics", John Wiley & Sons, 1976, pp. 705-767.

Boltger, et al.; "LCD substrate—the future process" International Glass Review, Issue 2—2000; 3 pages.

Bocko, Peter L. and Mitchell, Mark H., "AMLCD Glass Substrates—Foundation for High-Tech Displays" The GlassResearcher, vol. 12, No. 1, pp. 26-29, 2002.

* cited by examiner

U.S. Patent

Jan. 2, 2007

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US 7,155,935 B2

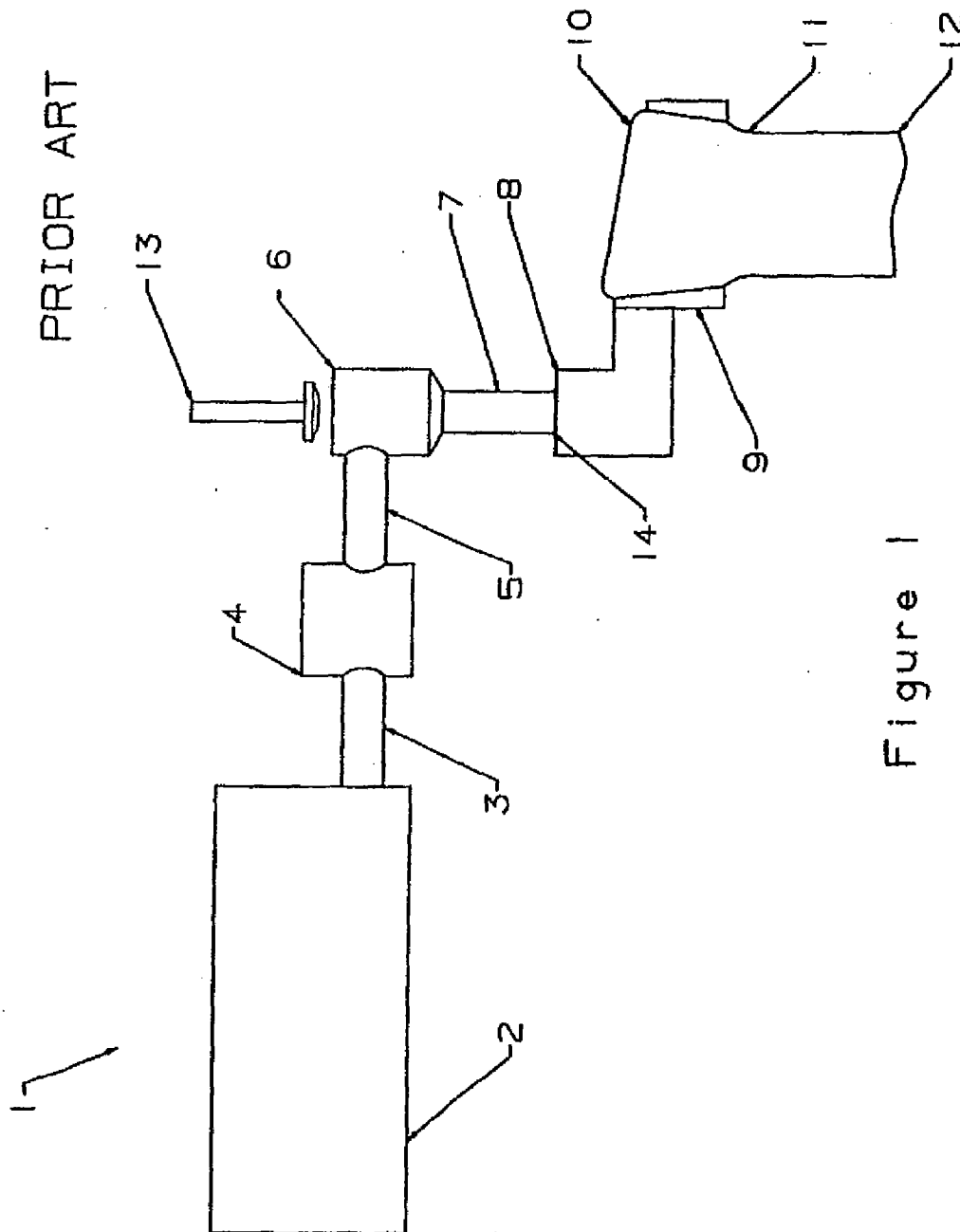
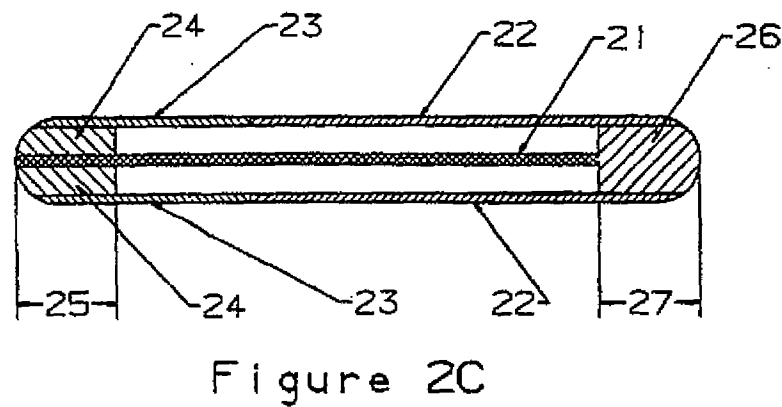
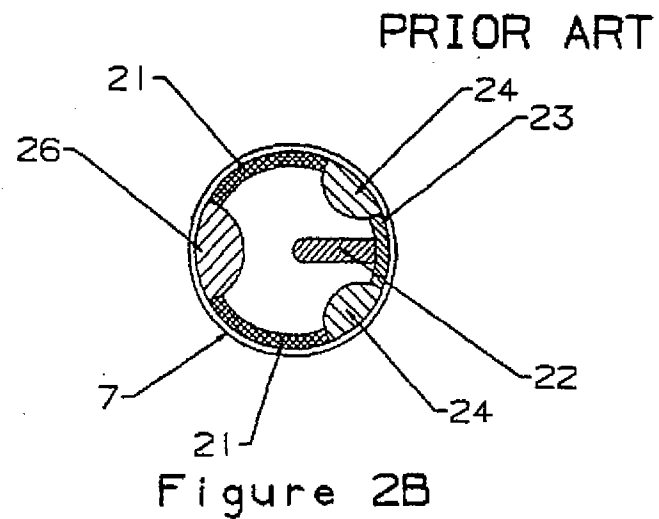
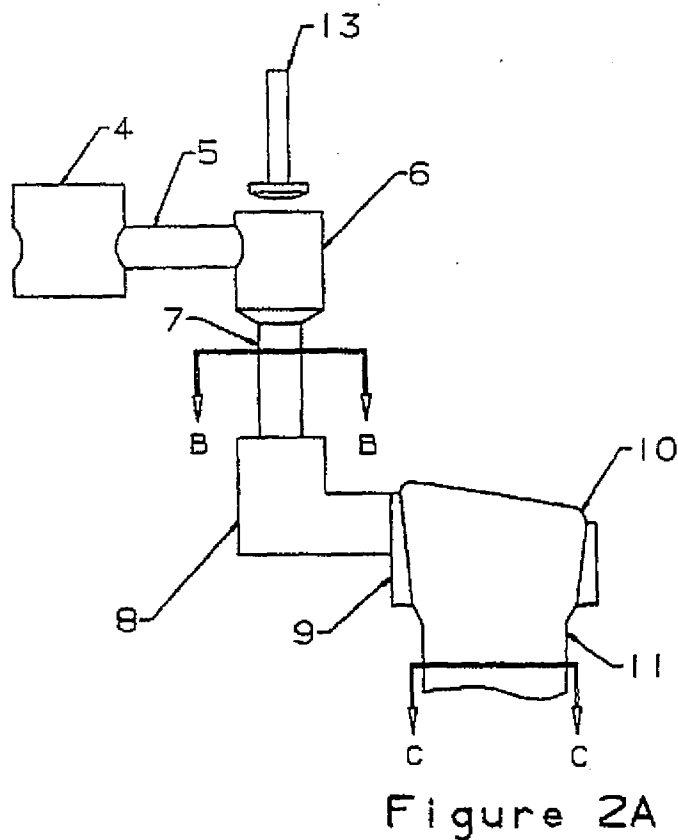
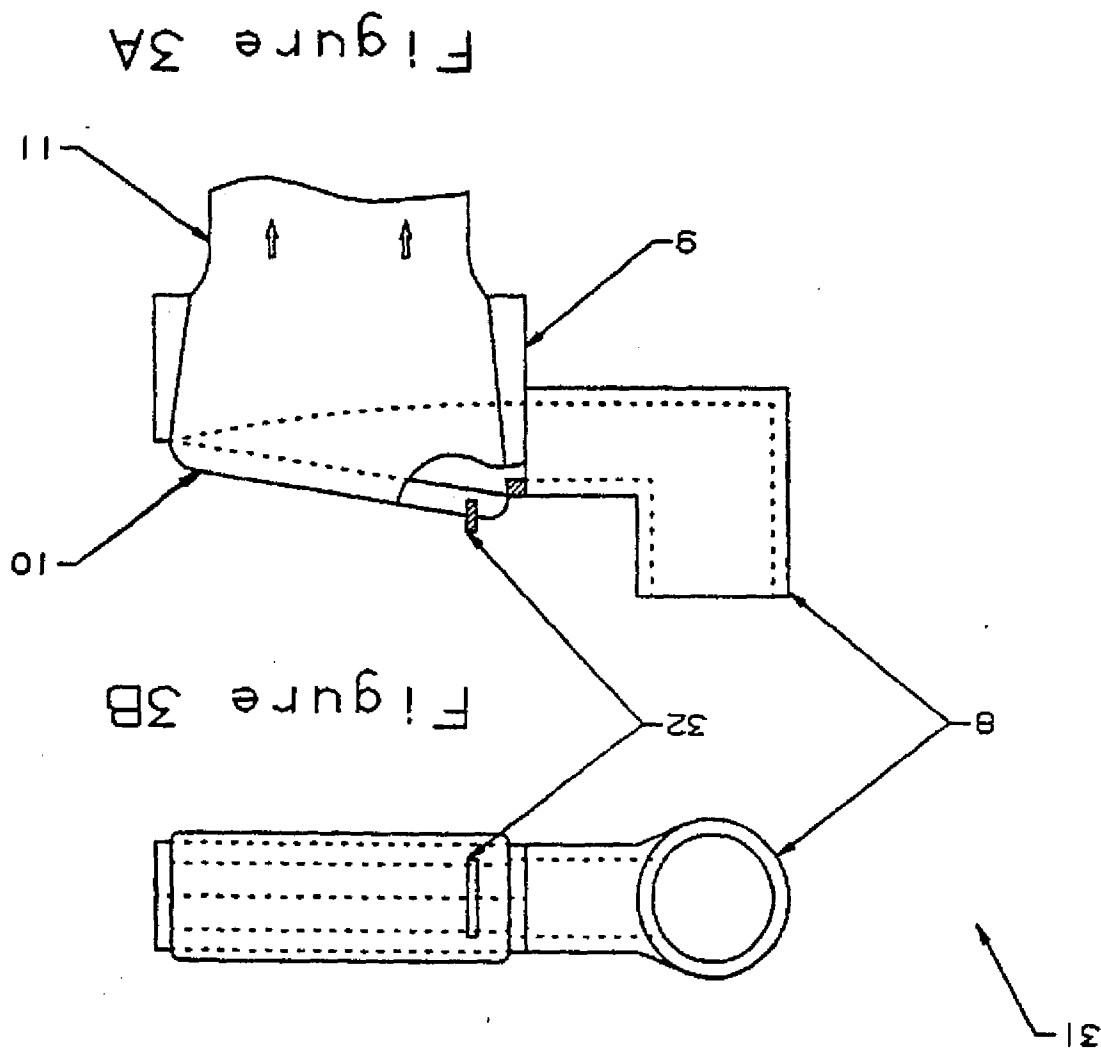
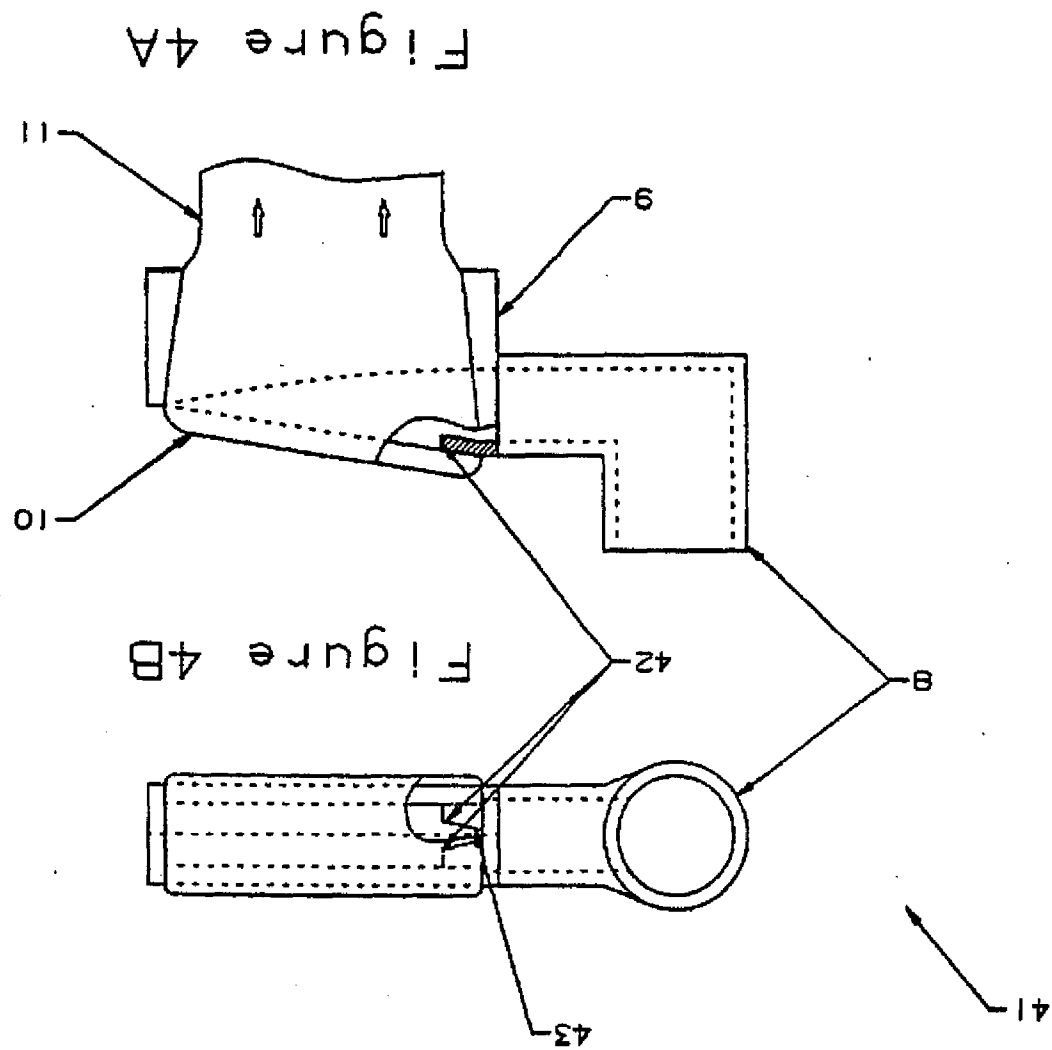


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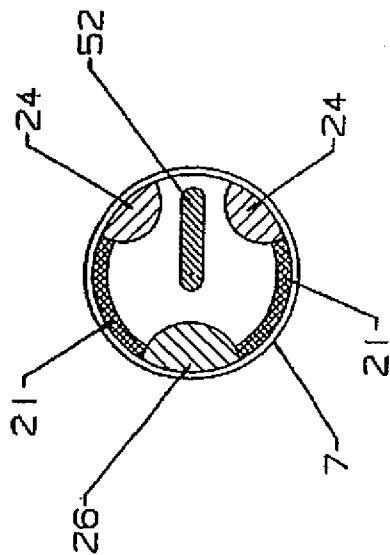


Figure 5B

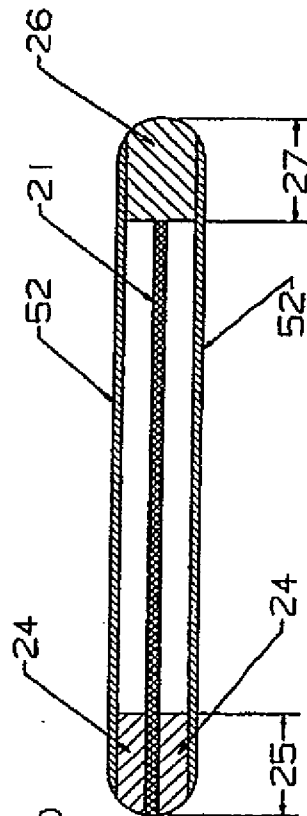


Figure 5C

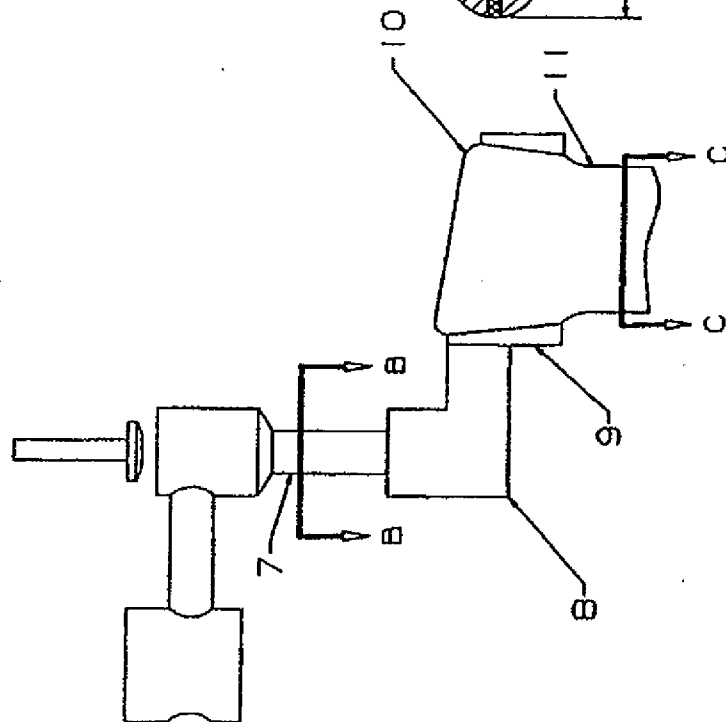


Figure 5A

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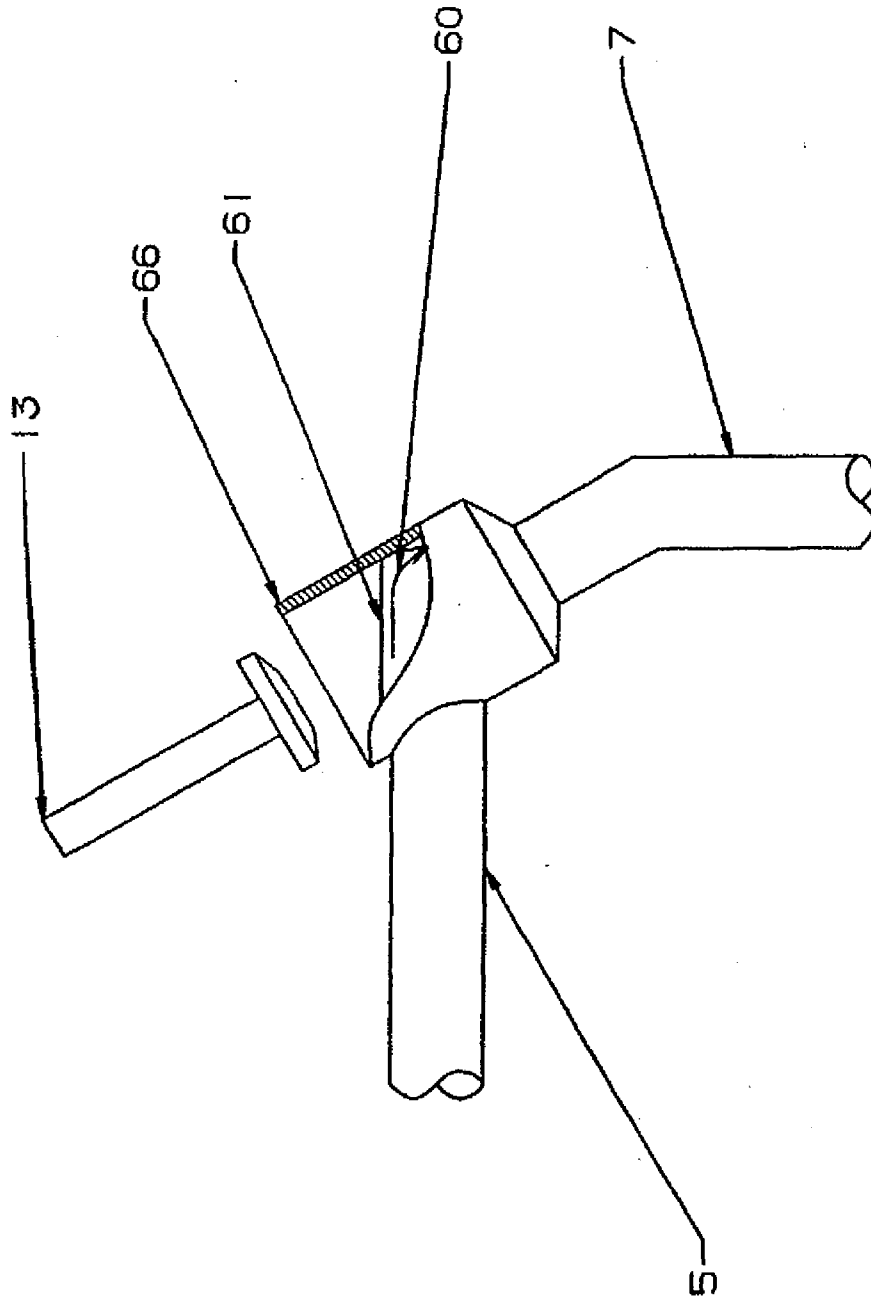


Figure 6

EXHIBIT B

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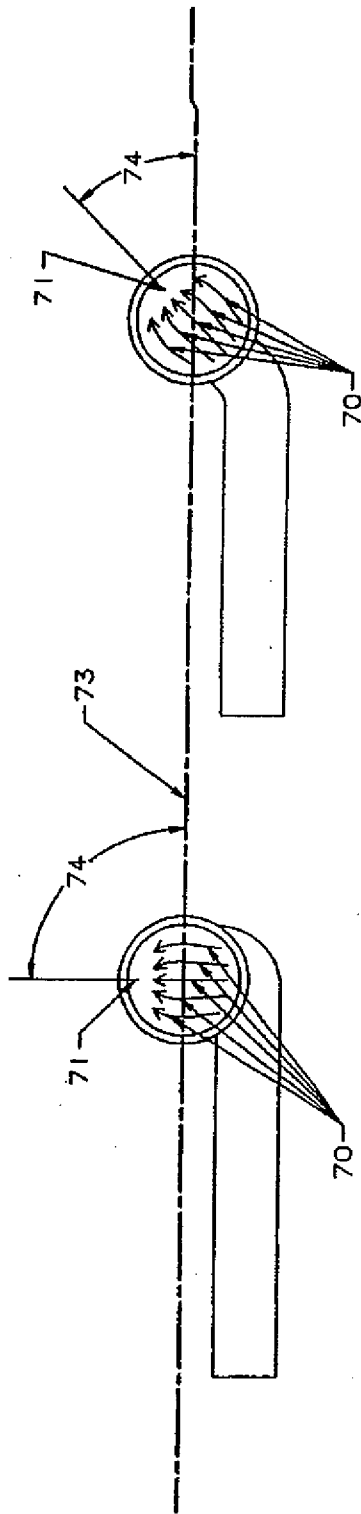


Figure 7C

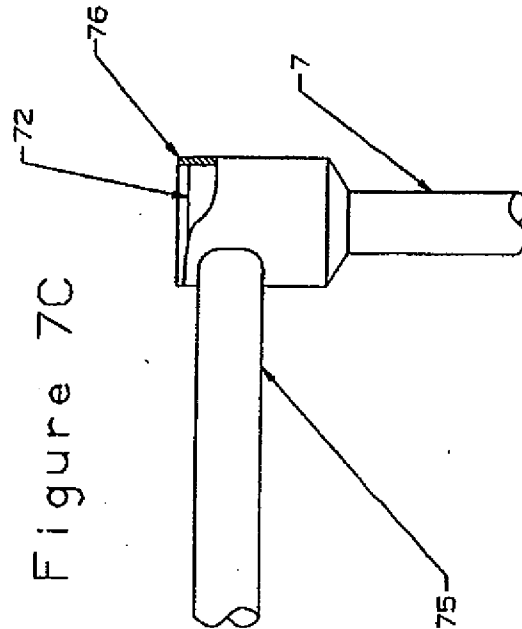


Figure 7D

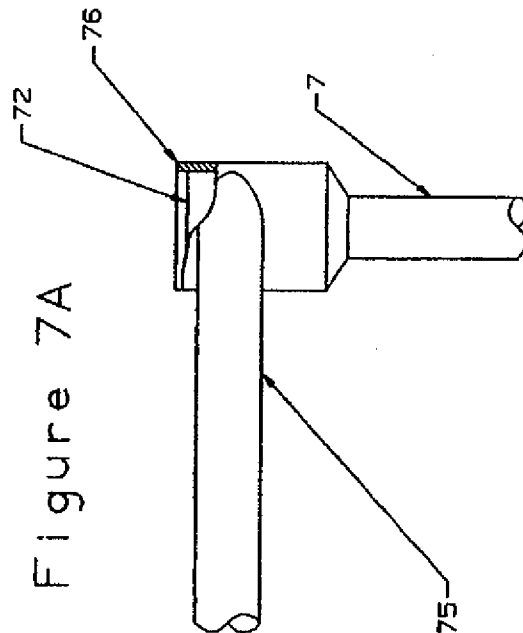


Figure 7B

EXHIBIT B

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PRIOR ART

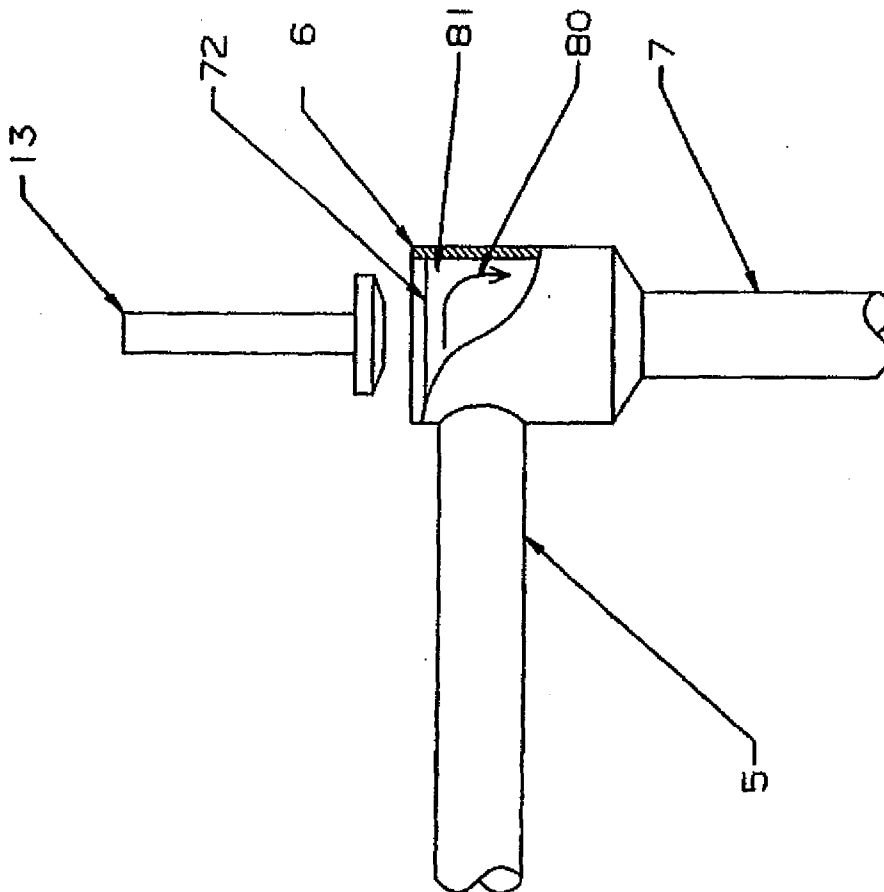


Figure 8

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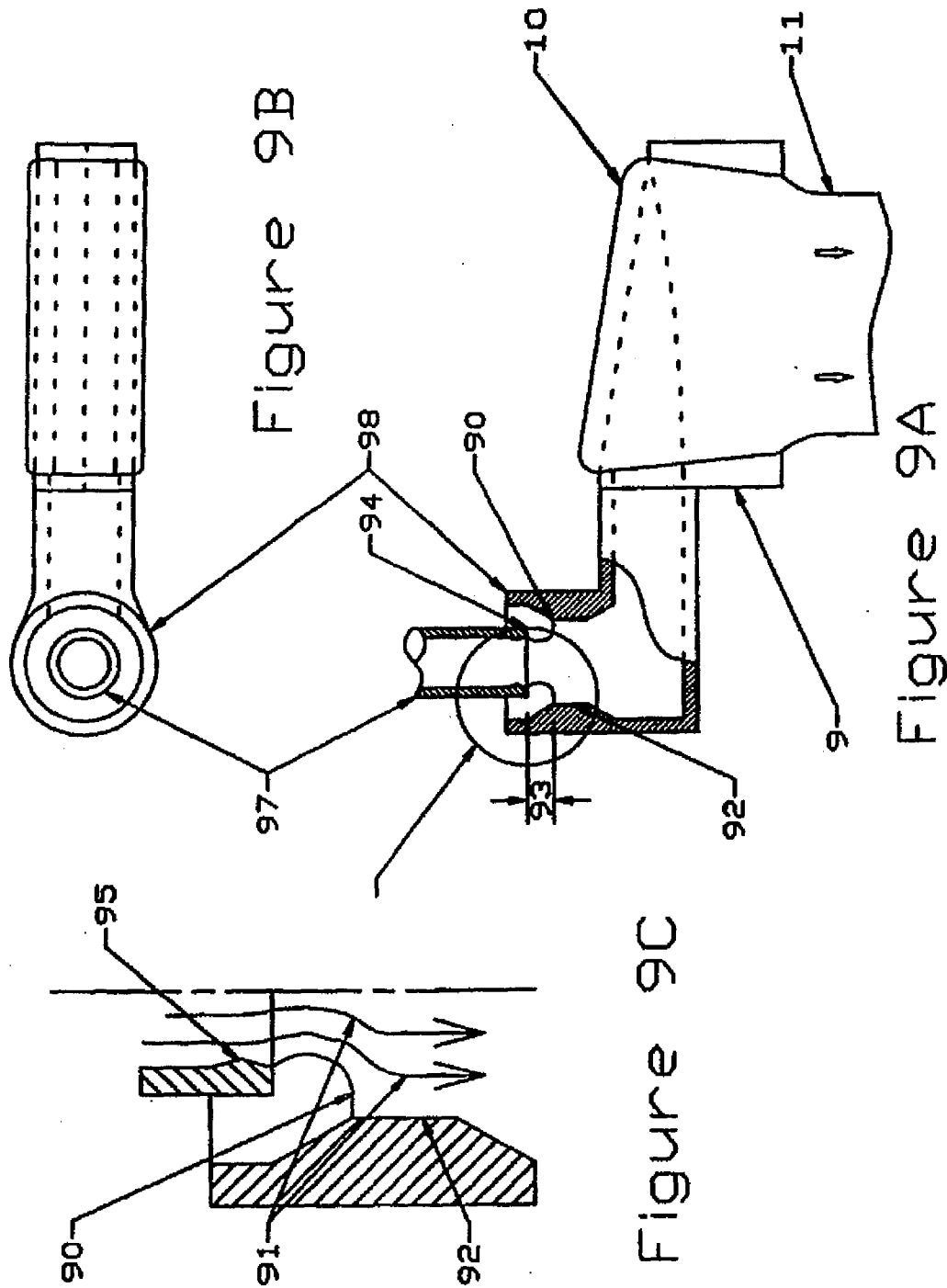


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PRIOR ART

Figure 10B

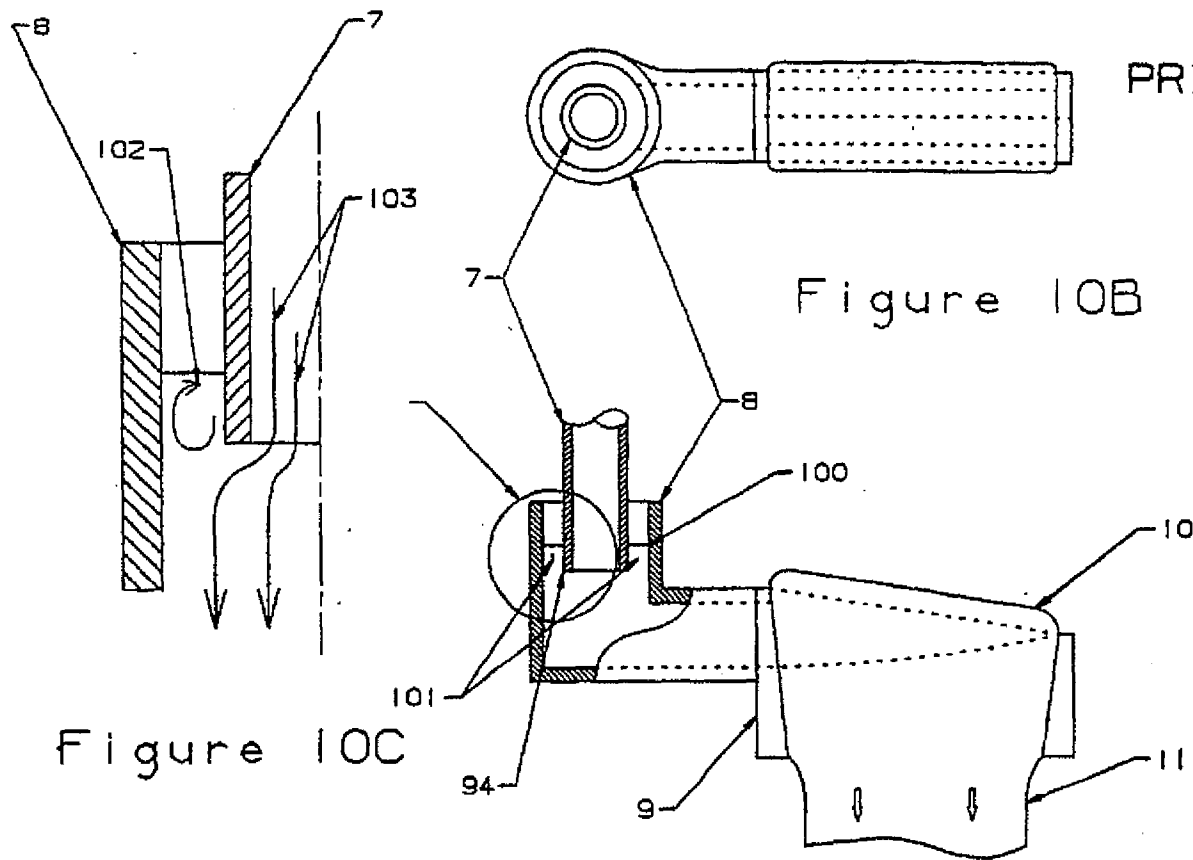


Figure 10C

Figure 10A

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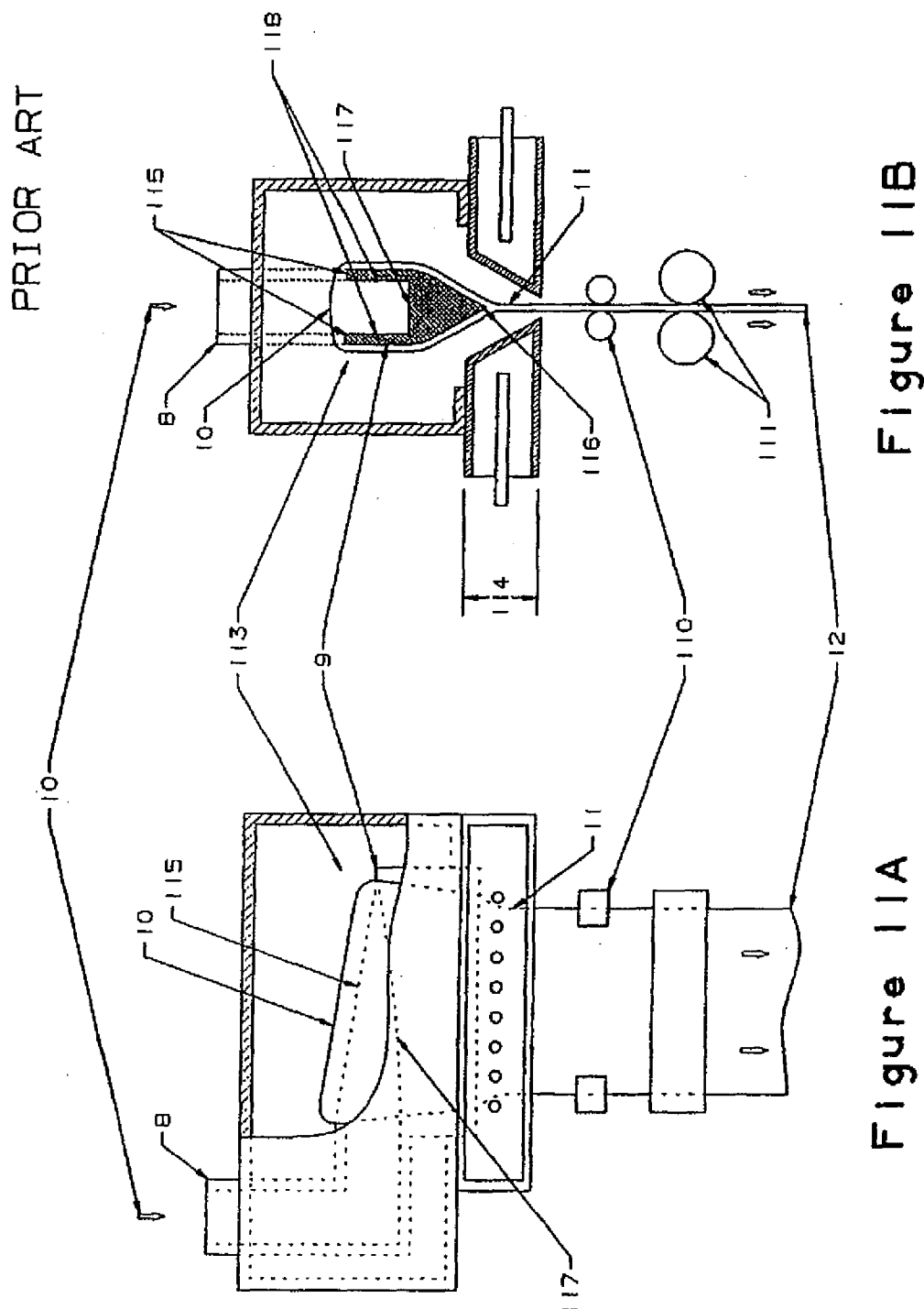


Figure 11B

Figure 11A

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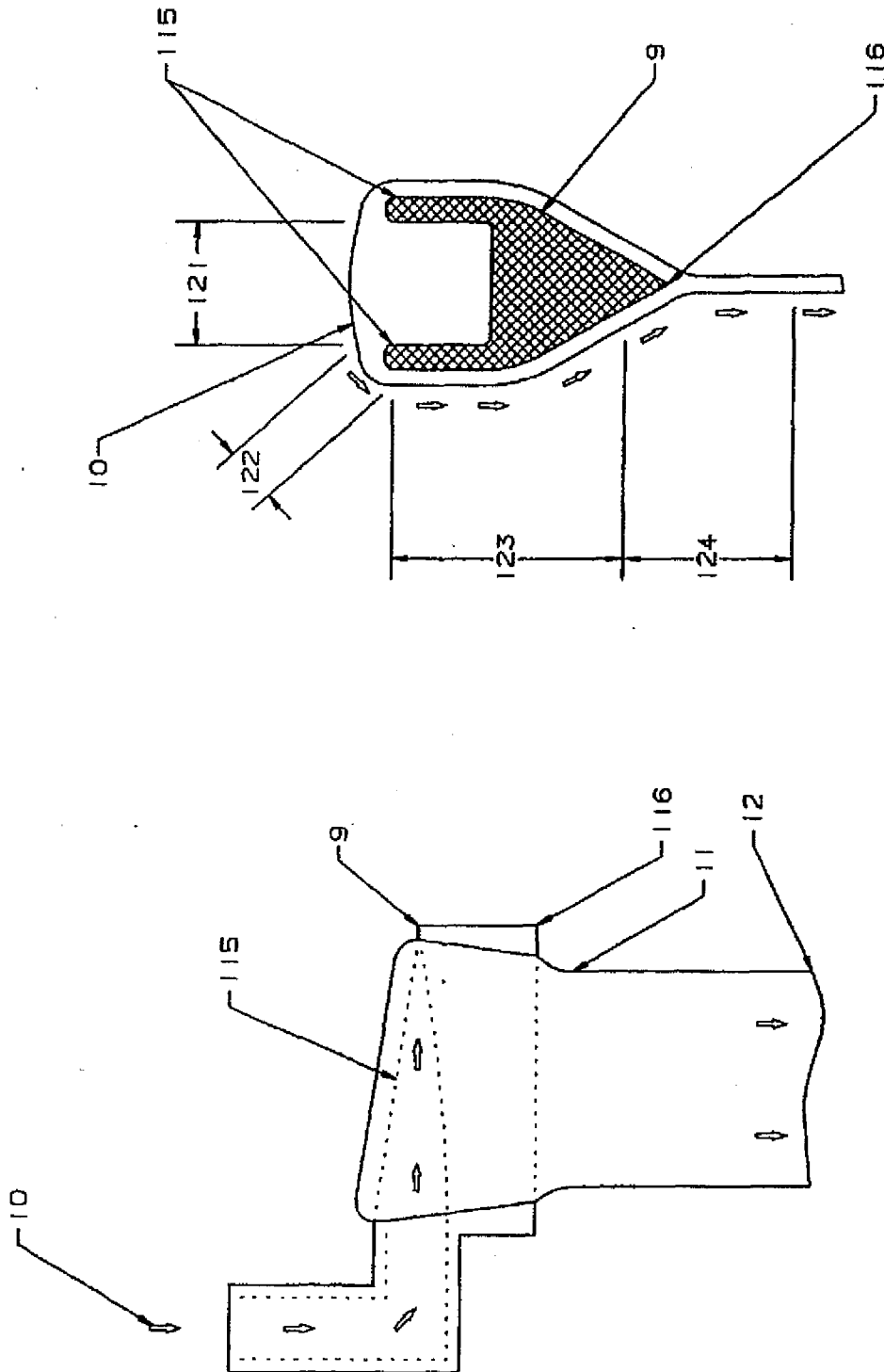


Figure 12B

Figure 12A

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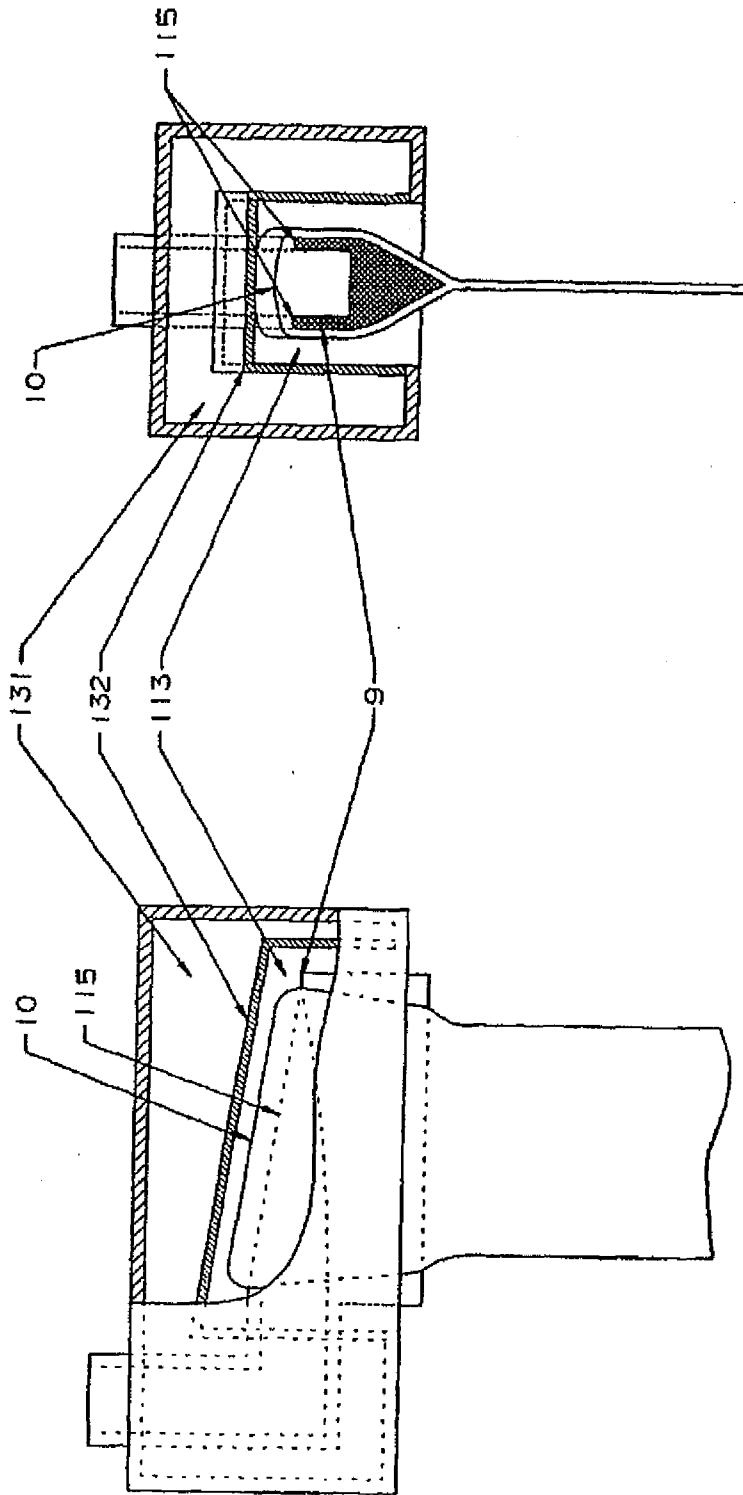


Figure 13B

Figure 13A

EXHIBIT B

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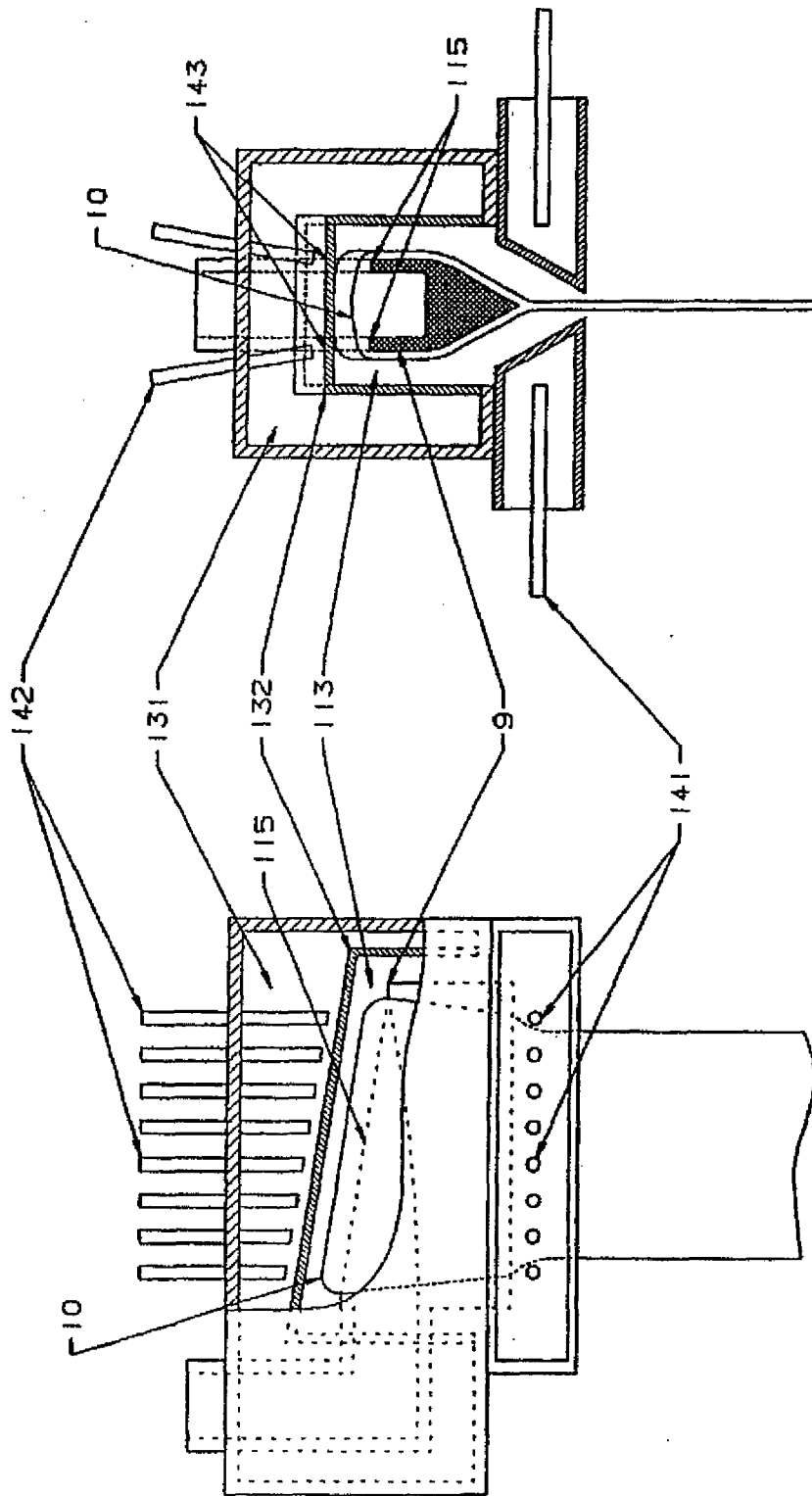


Figure 14B

Figure 14A

EXHIBIT B

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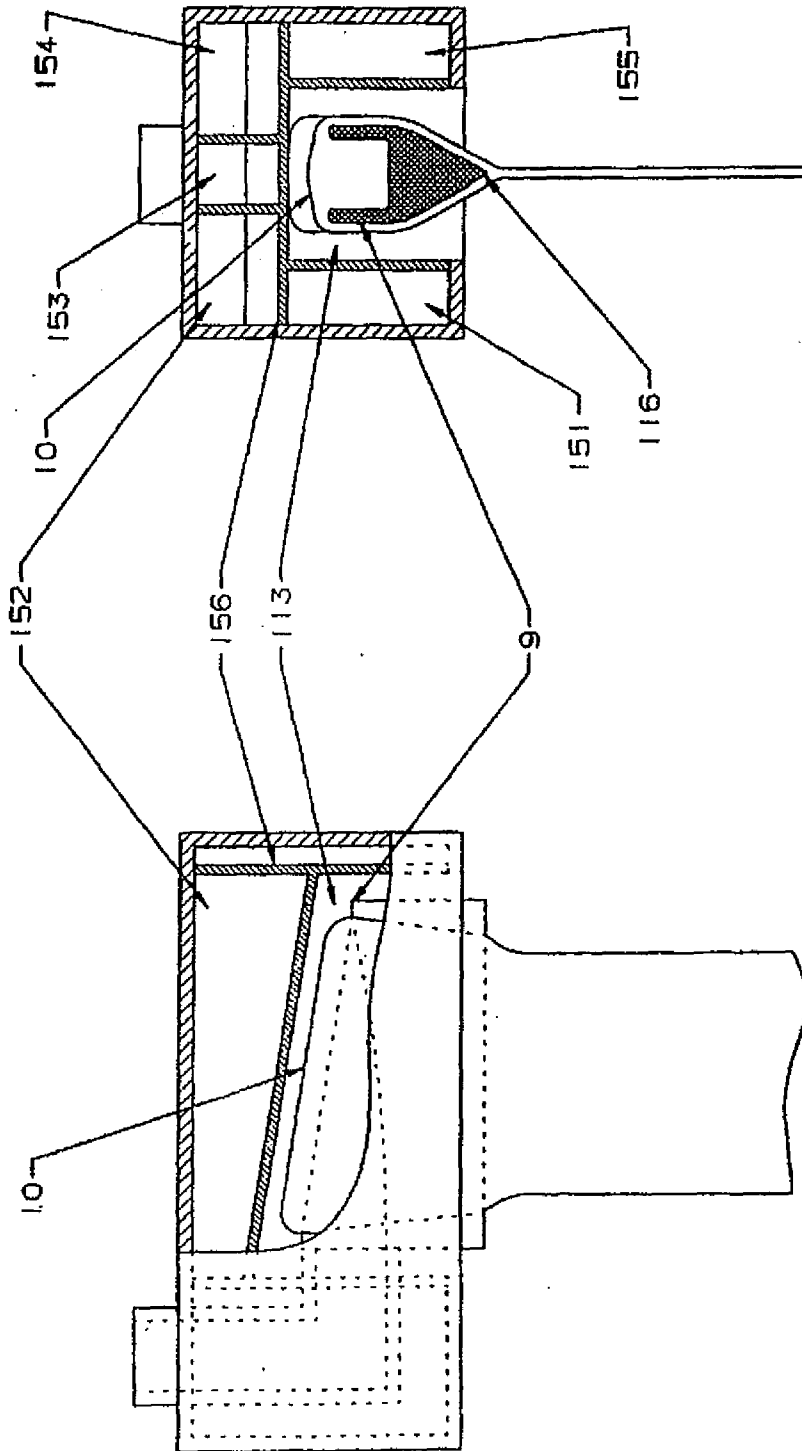


Figure 15B

Figure 15A

EXHIBIT B

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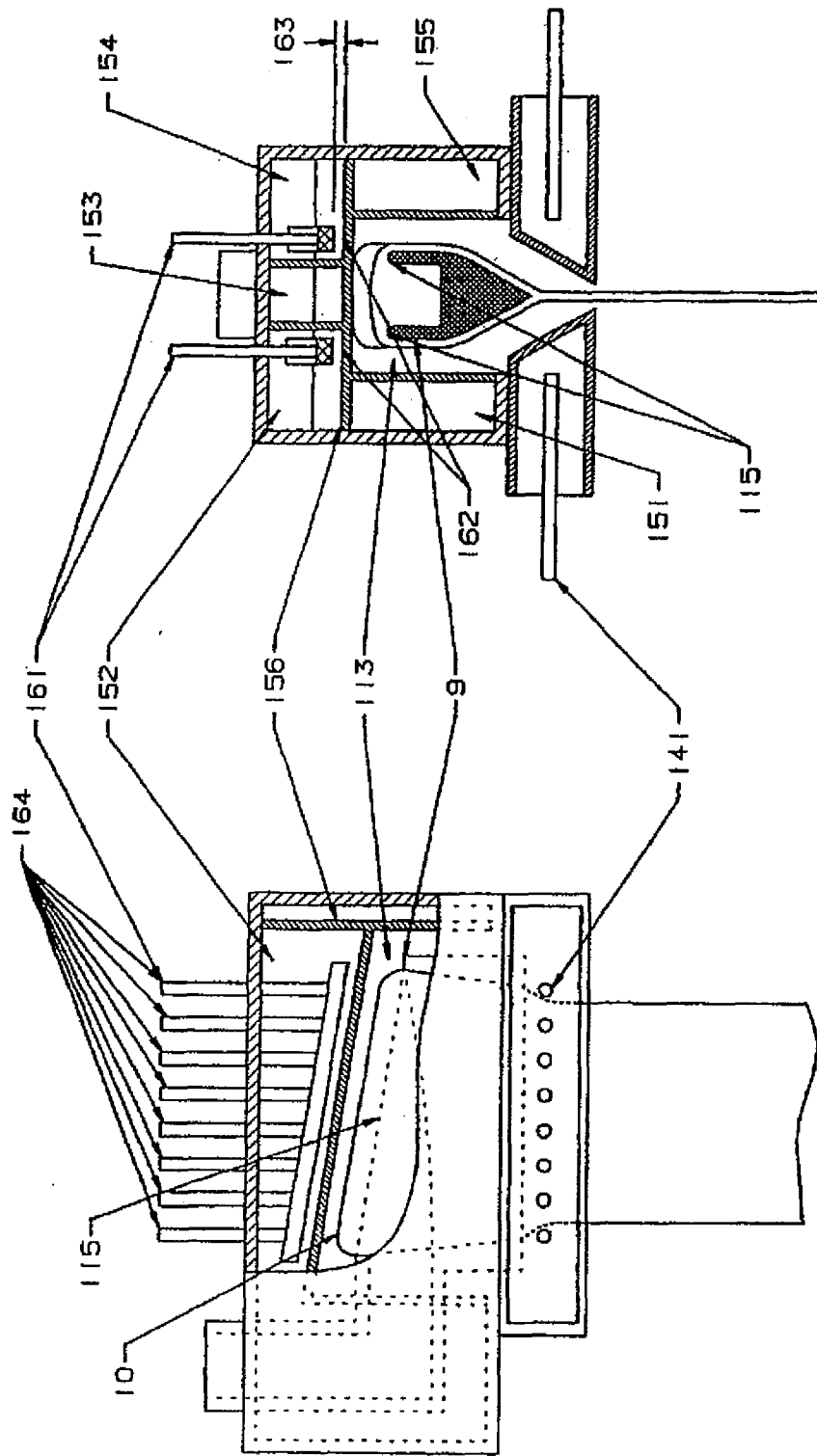


Figure 16B

Figure 16A

EXHIBIT B

PRIOR ART

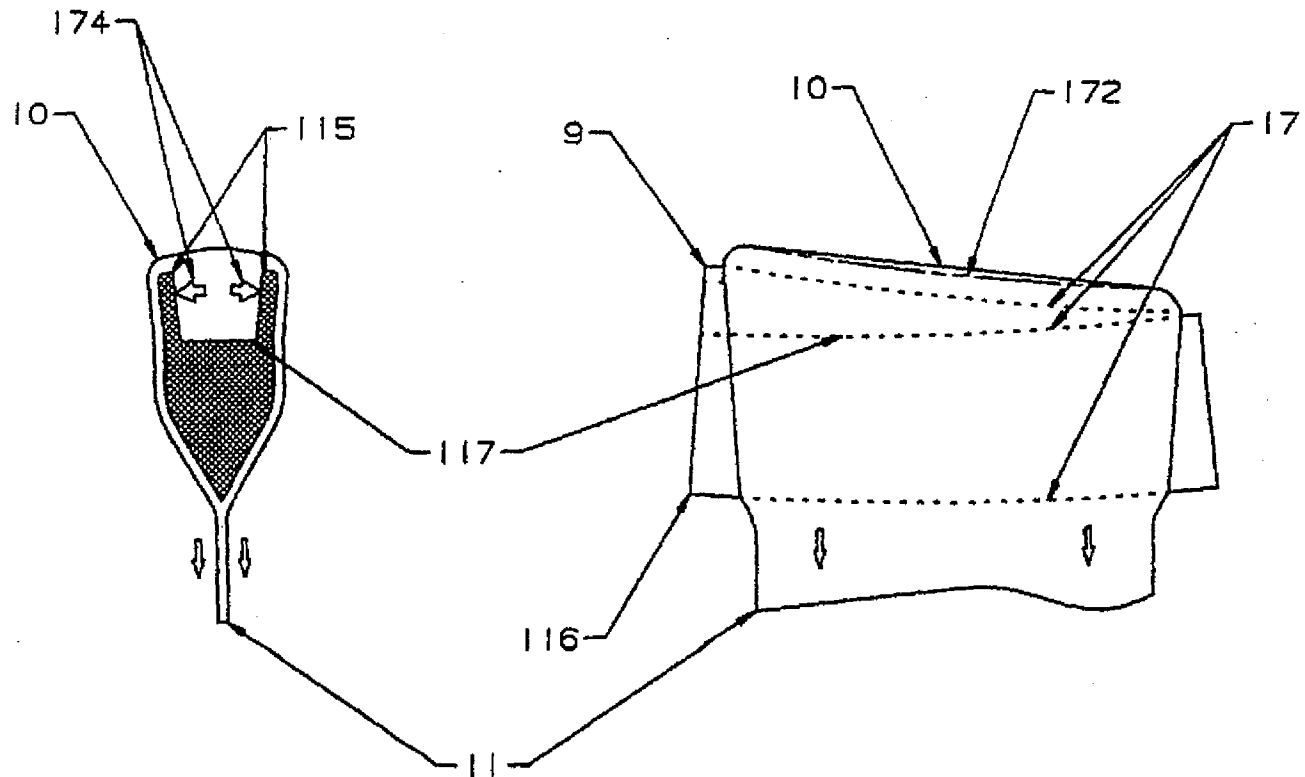
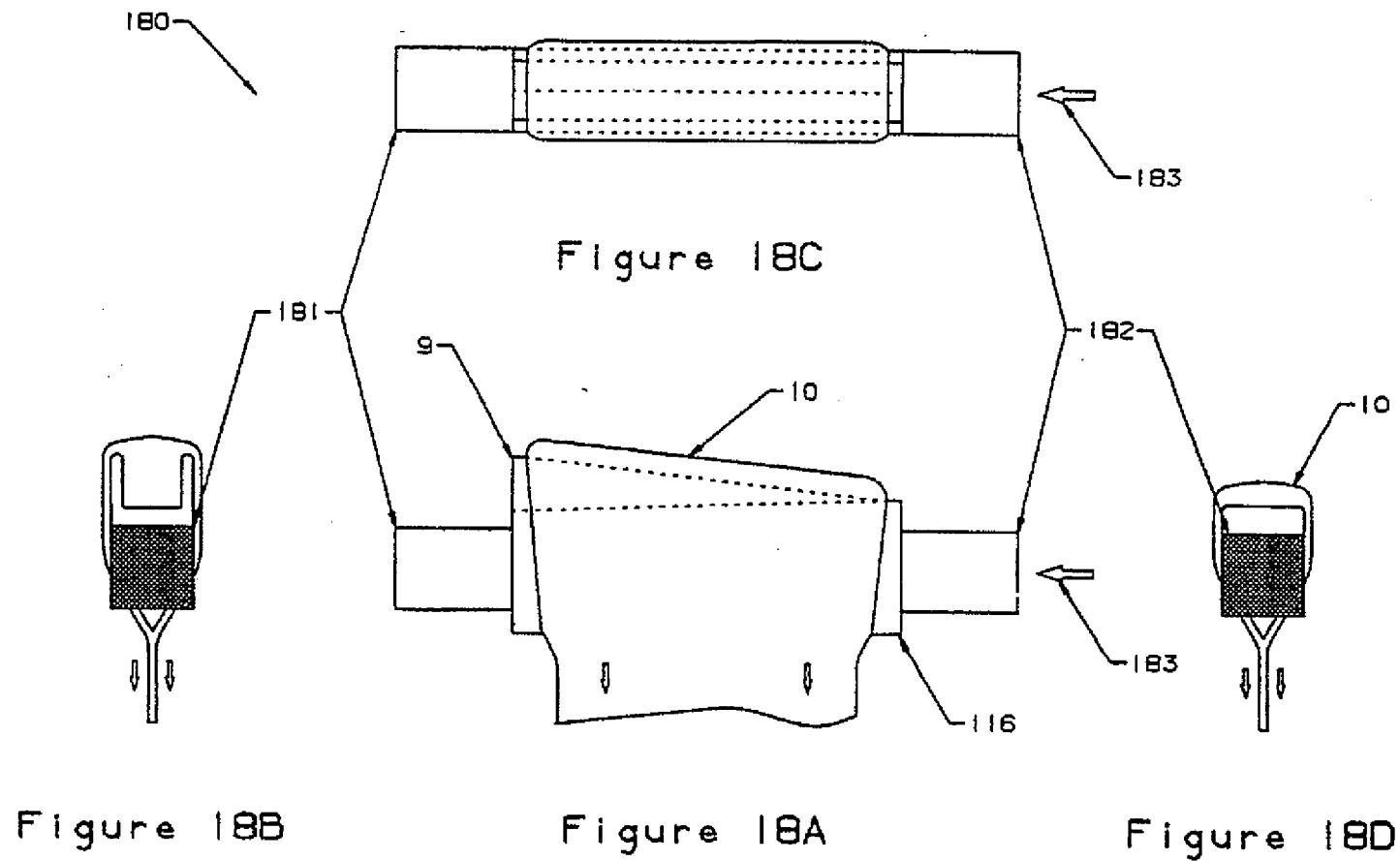


Figure 17B

Figure 17A

PRIOR ART



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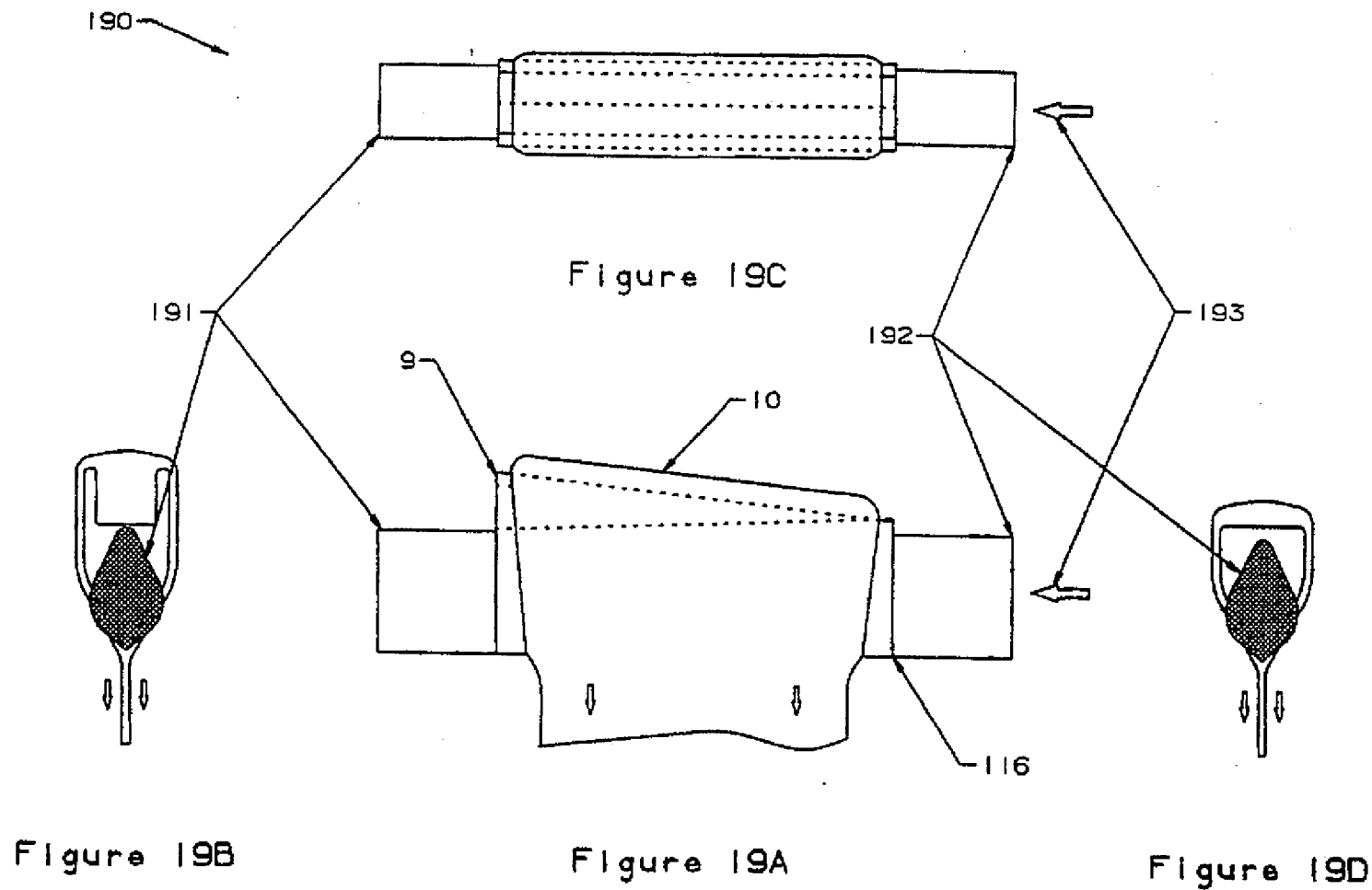


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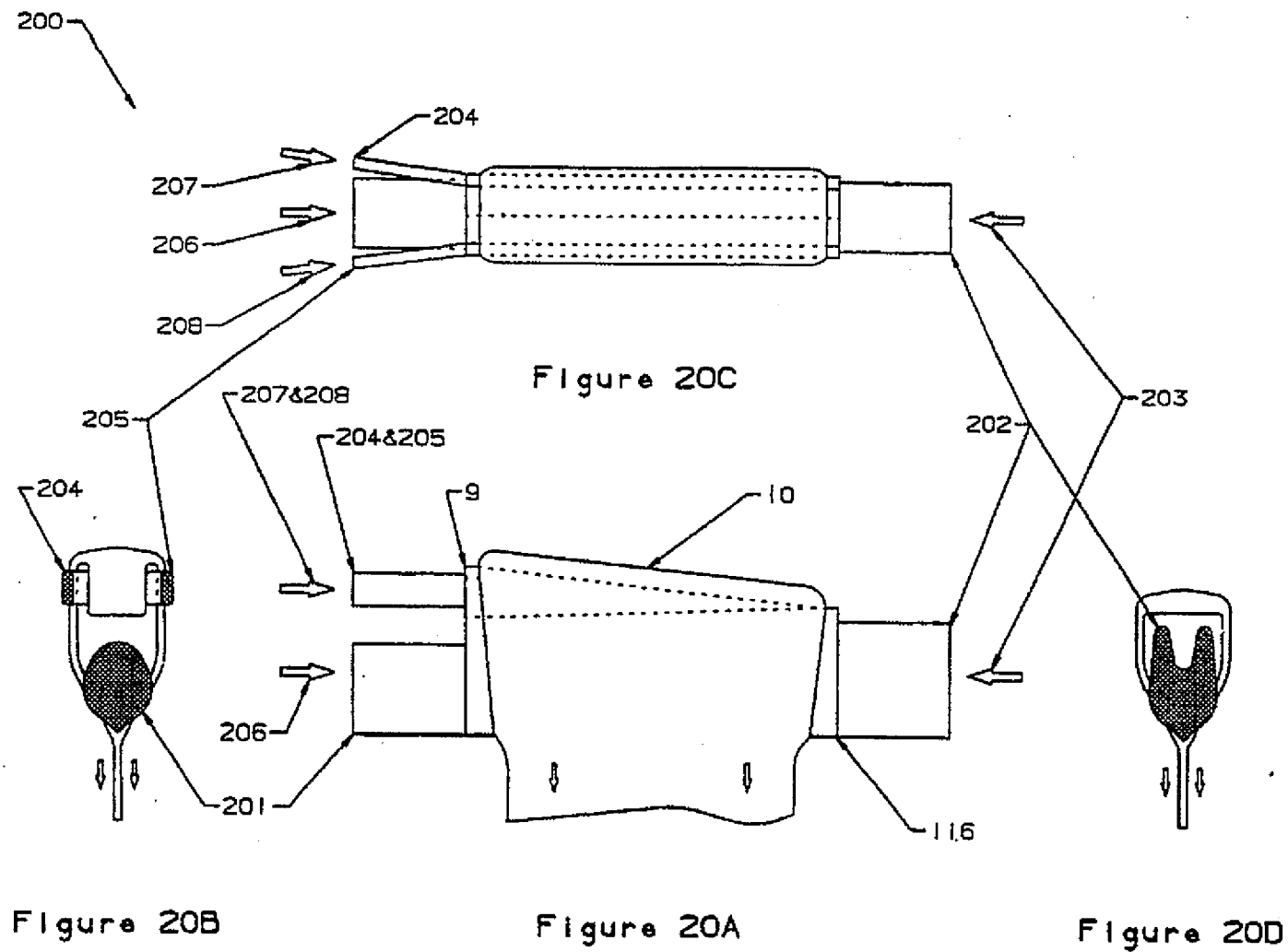


EXHIBIT B

PRIOR ART

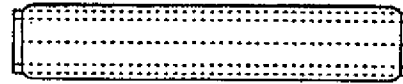


Figure 21B

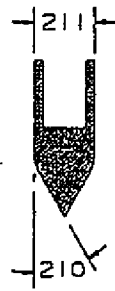


Figure 21C

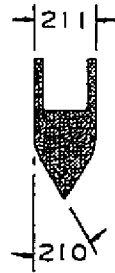


Figure 21D



Figure 21E



Figure 21F



Figure 21G

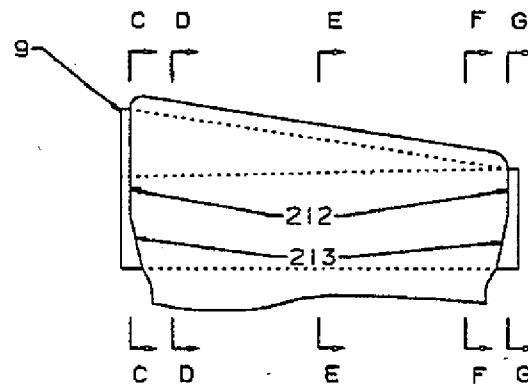


Figure 21A

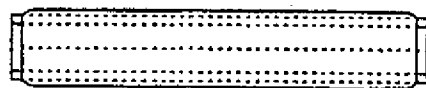


Figure 22B

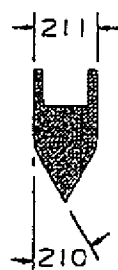
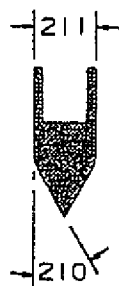
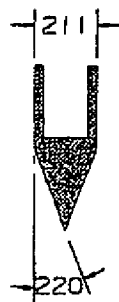


Figure 22C

Figure 22D

Figure 22E

Figure 22F

Figure 22G

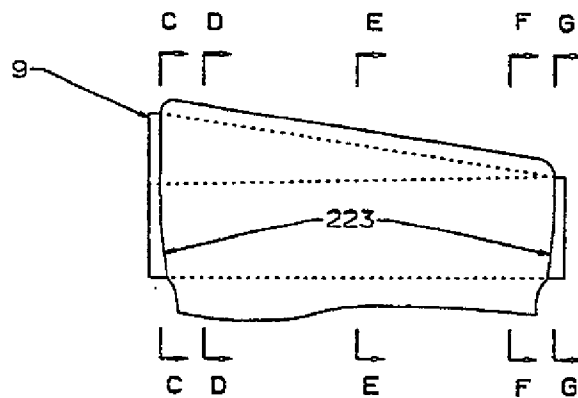


Figure 22A

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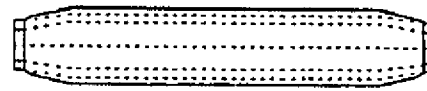


Figure 23B

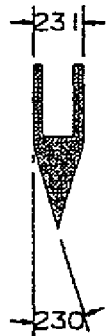


Figure 23C

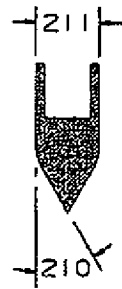


Figure 23D

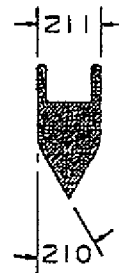


Figure 23E



Figure 23F



Figure 23G

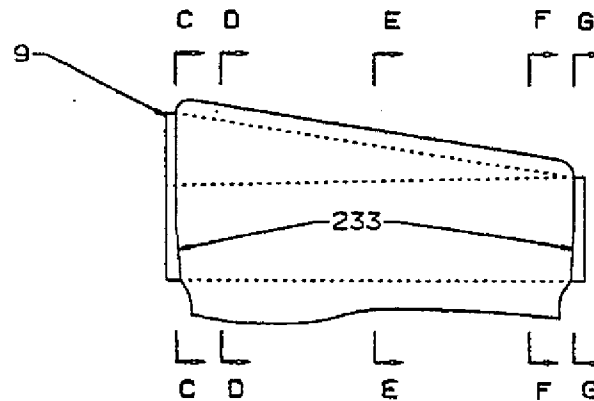


Figure 23A

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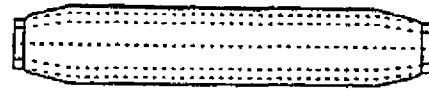


Figure 24B

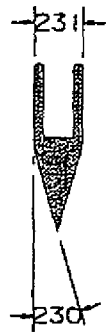


Figure 24C

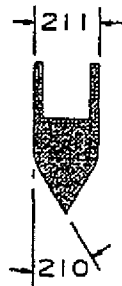


Figure 24D

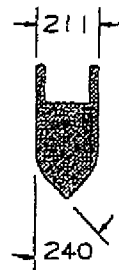


Figure 24E

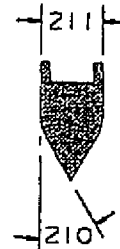


Figure 24F



Figure 24G

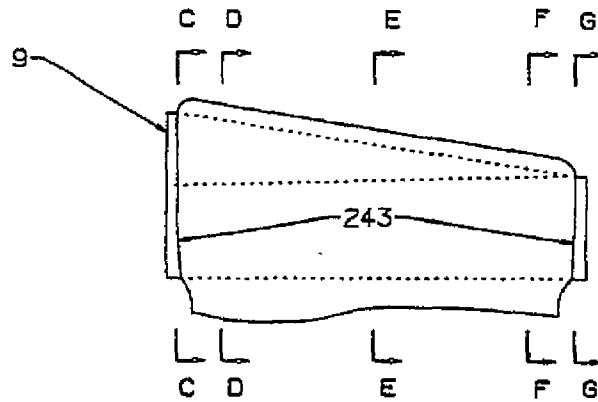


Figure 24A

EXHIBIT B

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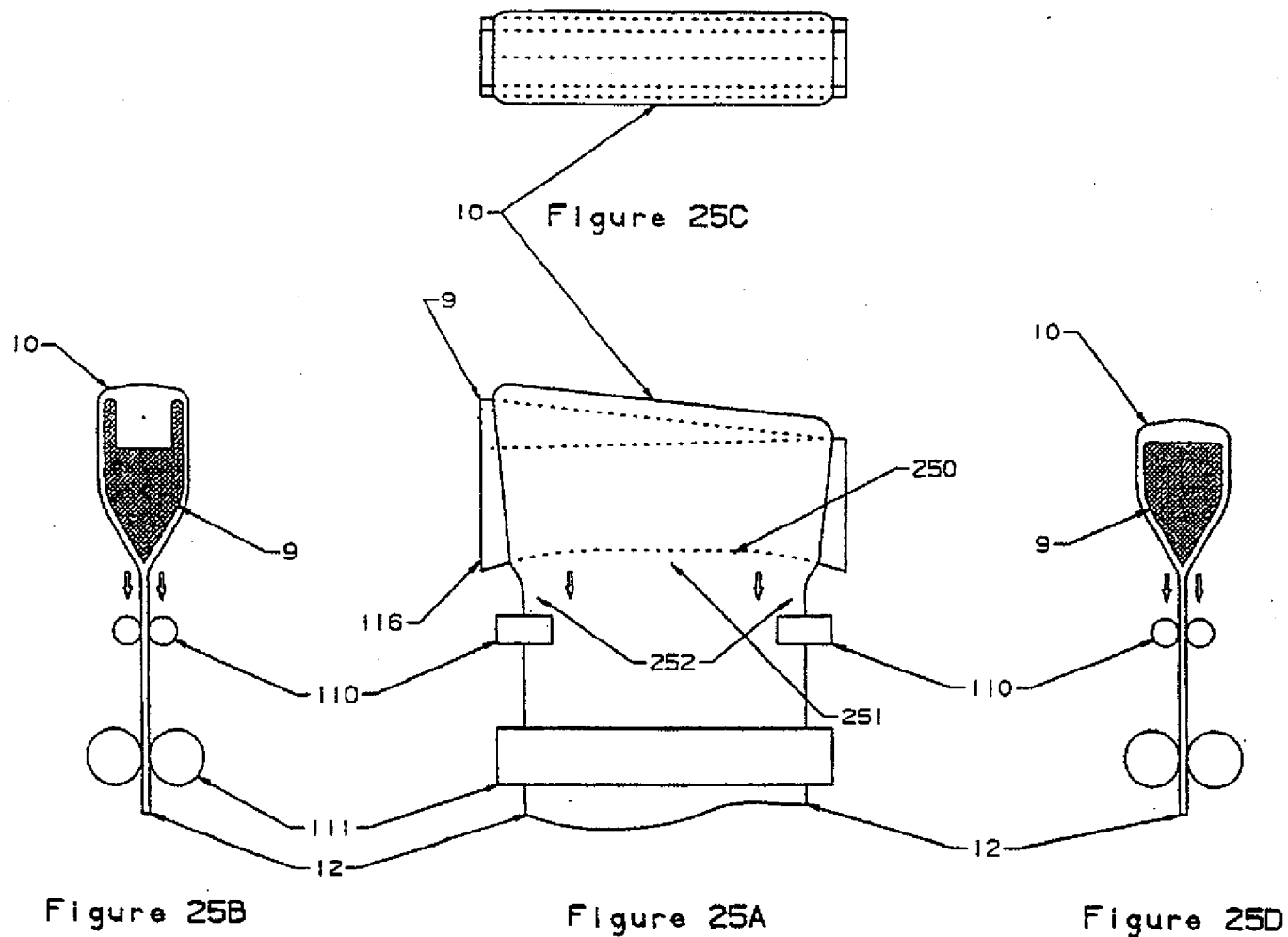


EXHIBIT B

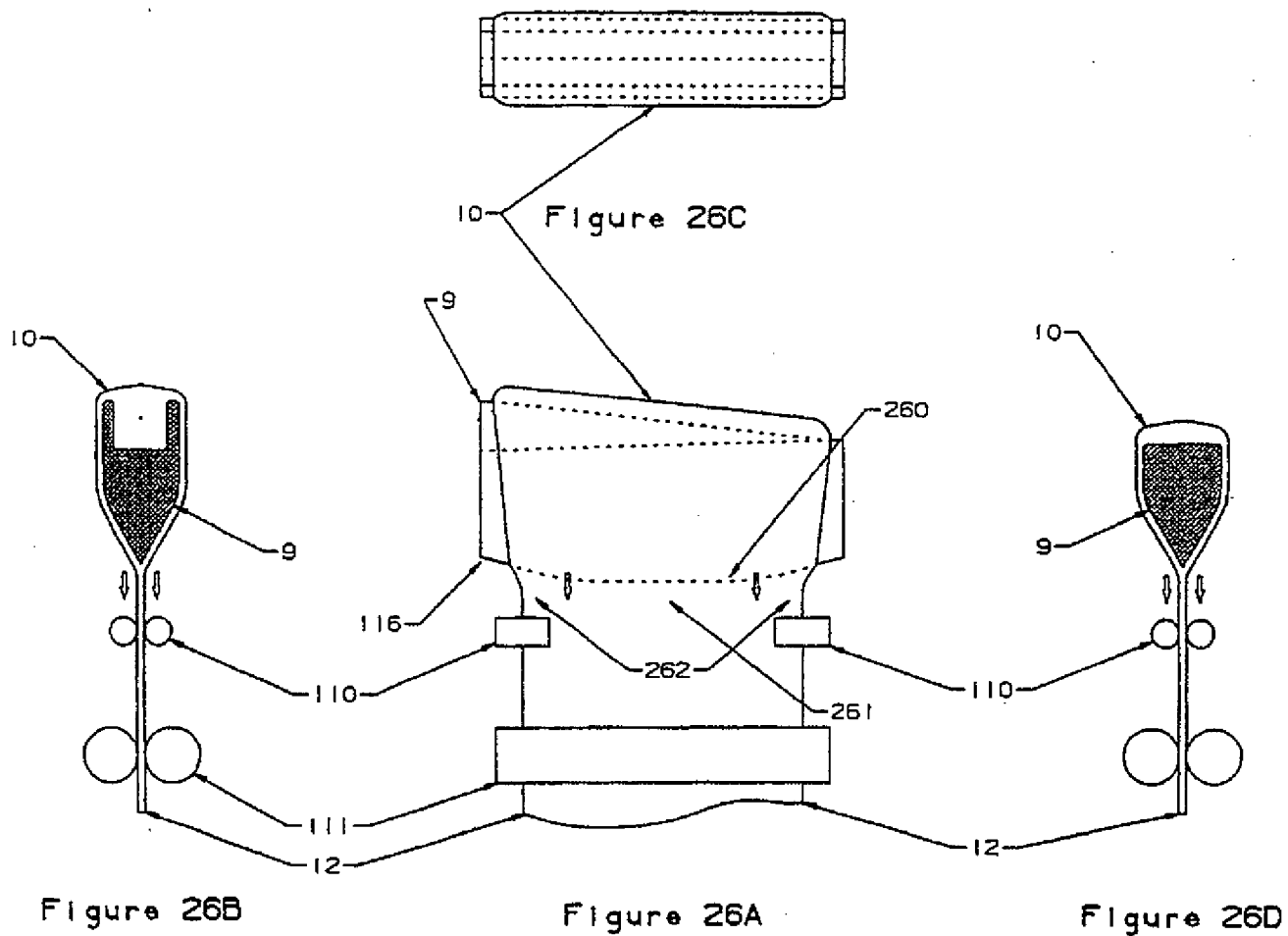
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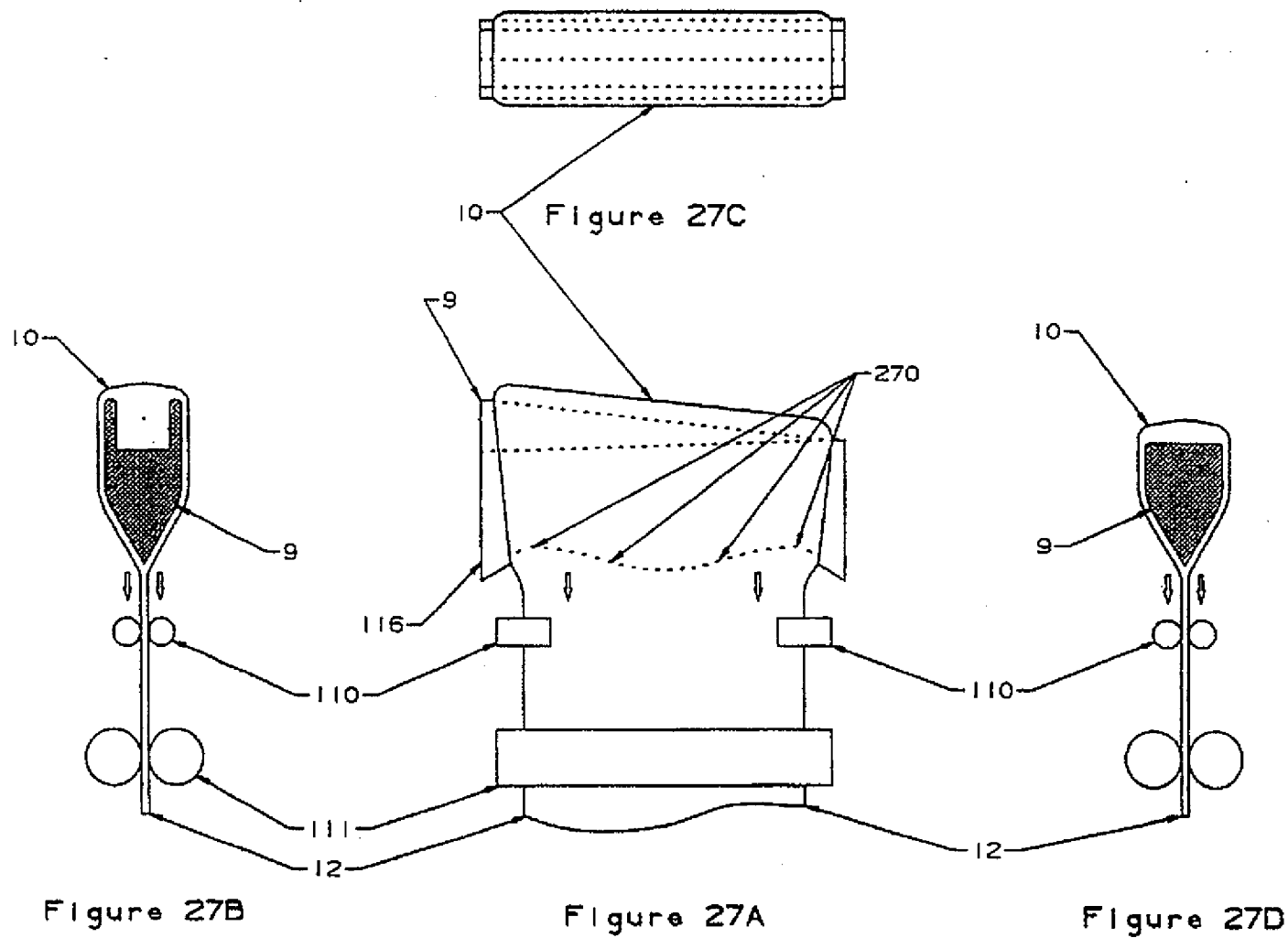
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PRIOR ART

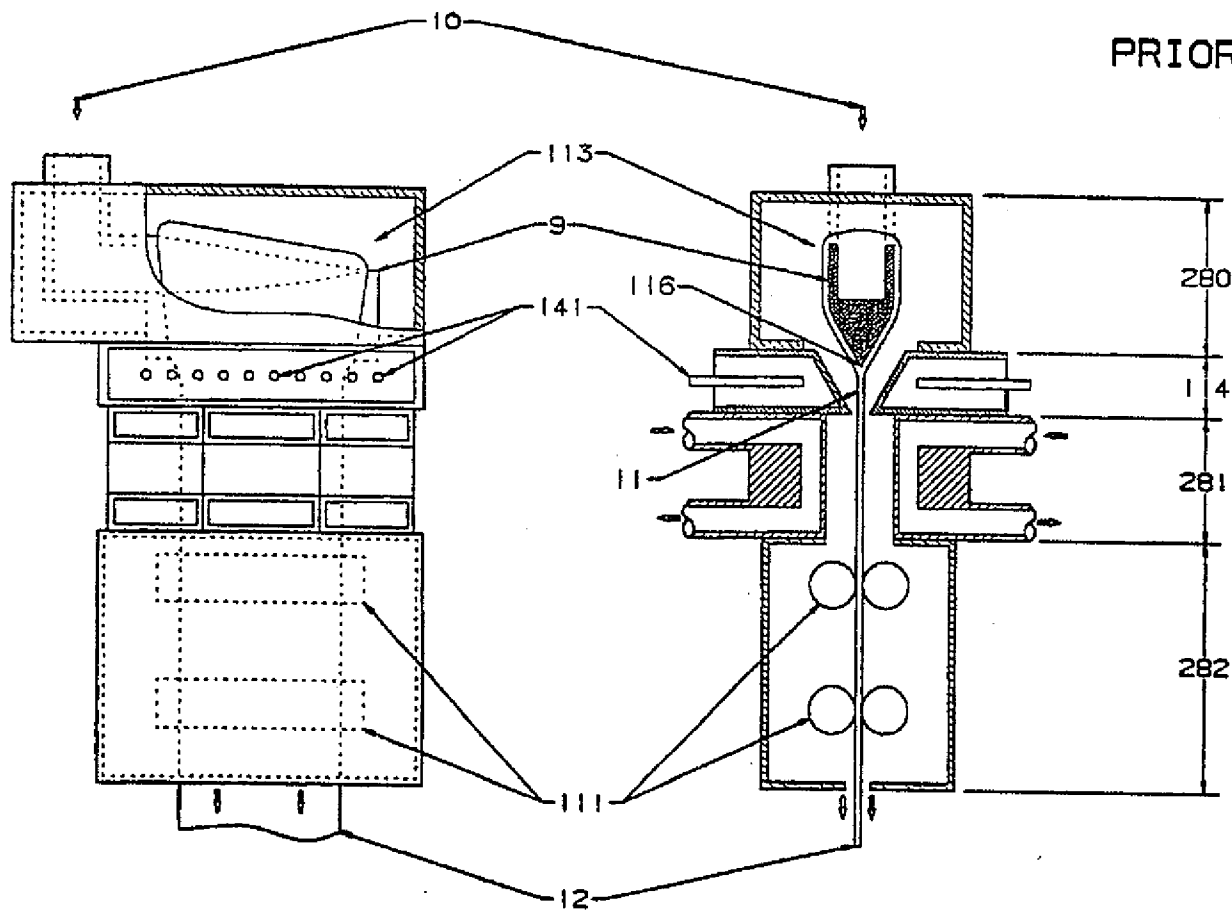


Figure 28A

Figure 28B

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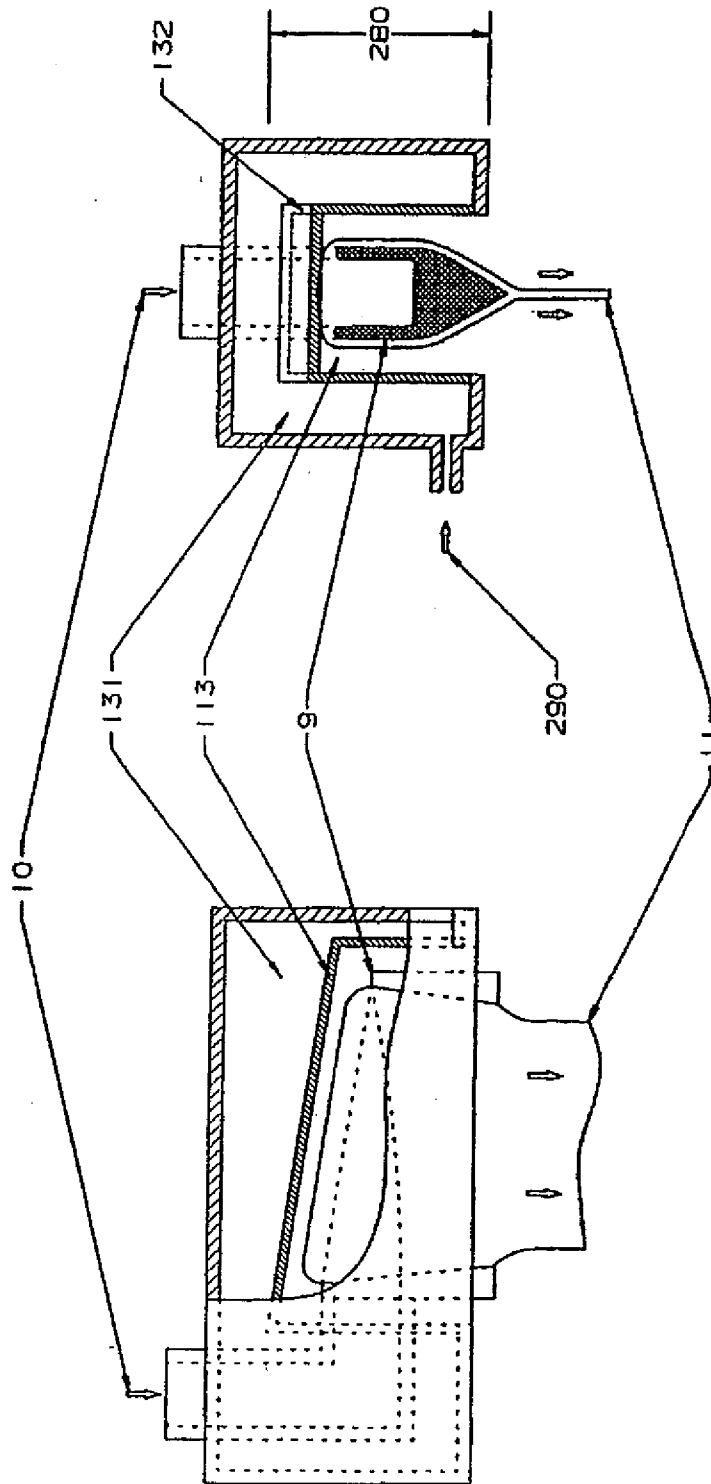


Figure 29B

Figure 29A

EXHIBIT B

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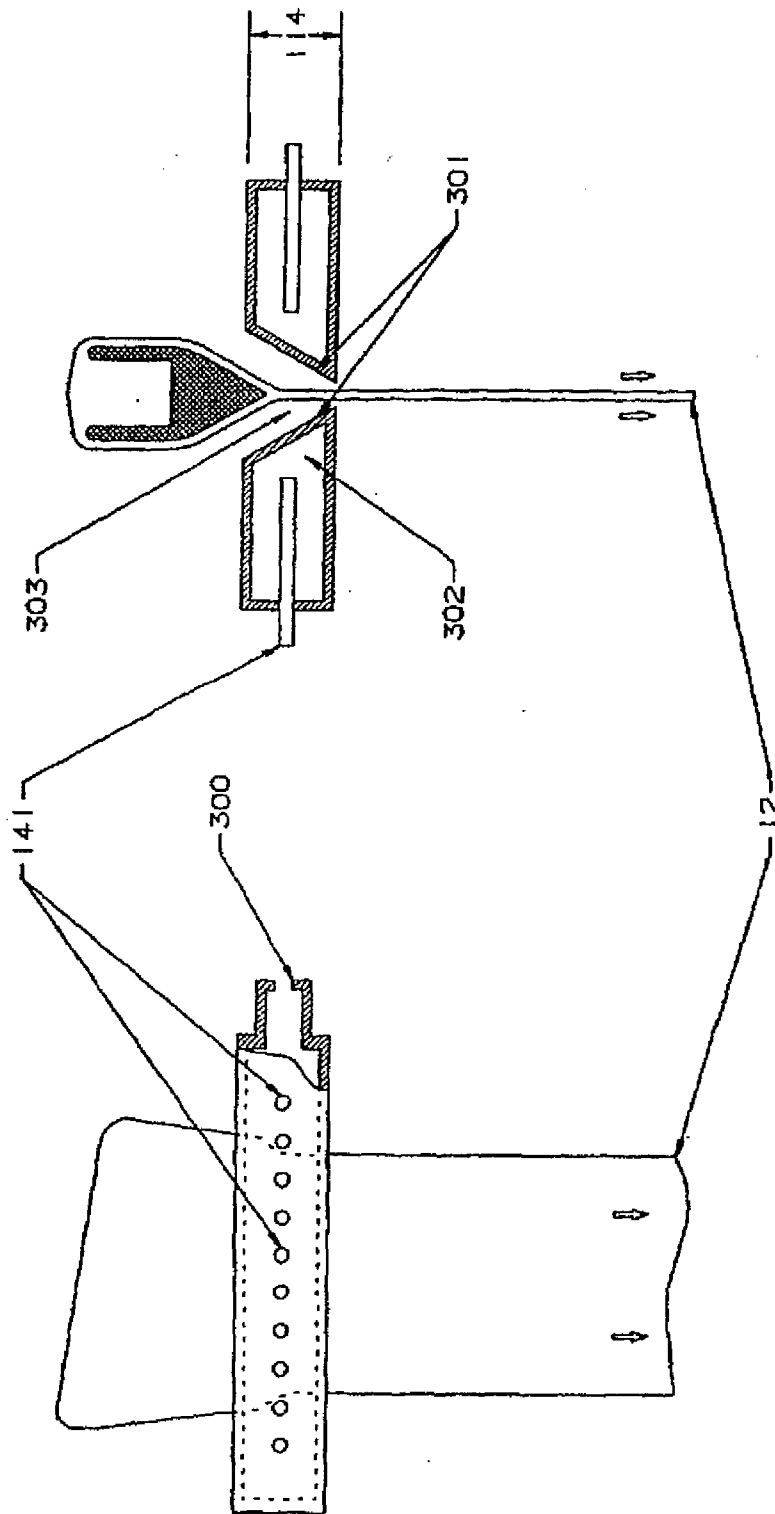


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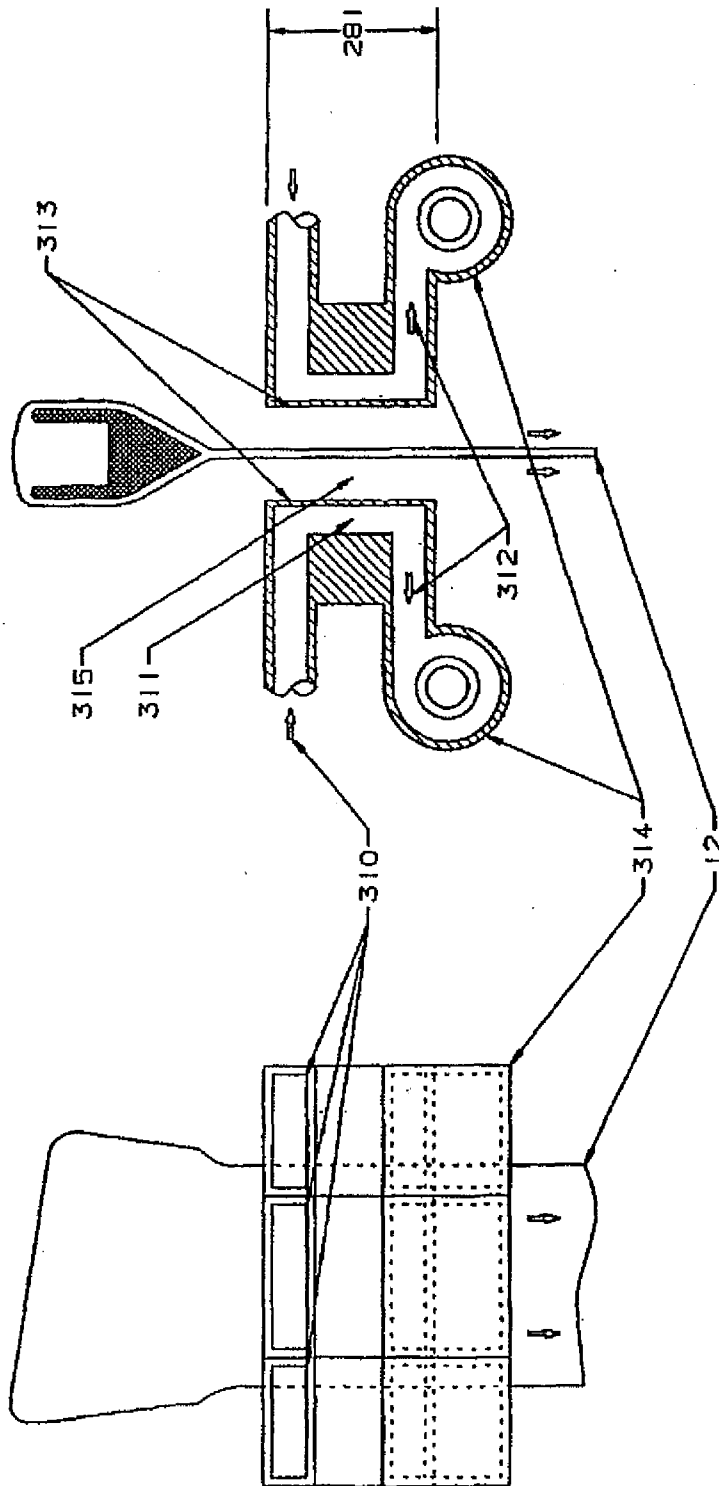


Figure 31B

Figure 31A

EXHIBIT B

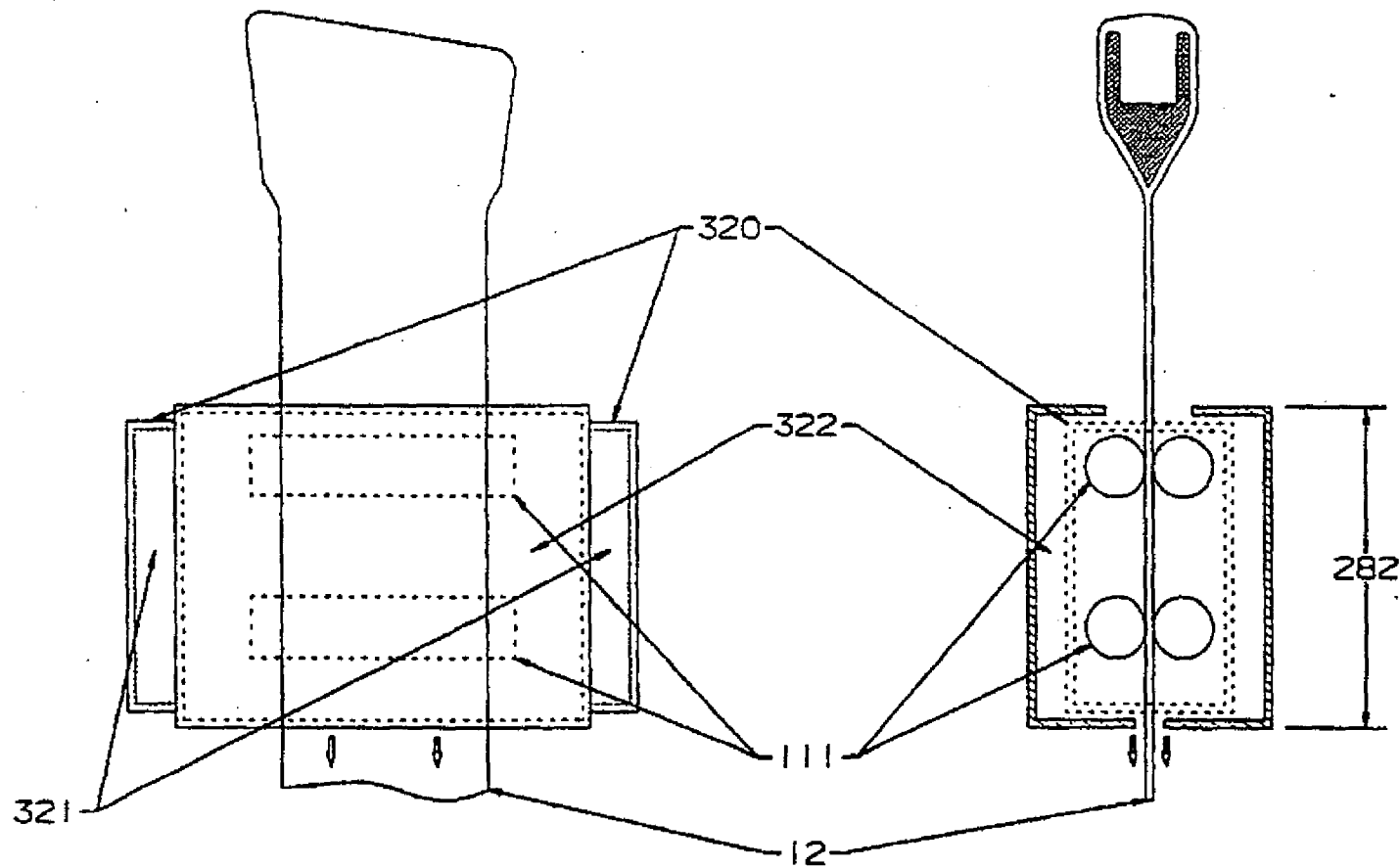


Figure 32A

Figure 32B

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SHEET GLASS FORMING APPARATUS

This is a divisional patent application of application Ser. No. 10/214,904, filed Aug. 8, 2002, entitled "OVERFLOW DOWNDRAW GLASS FORMING METHOD AND APPARATUS", now U.S. Pat. No. 6,889,526, issued May 10, 2005. The aforementioned application is hereby incorporated herein by reference.

That application claims an invention that was disclosed in one of the following provisional applications:

- 1) Provisional Application No. 60/310,989, filed Aug. 8, 2001, entitled "SHEET GLASS FORMING DEVICE";
- 2) Provisional Application No. 60/316,676, filed Aug. 29, 2001, entitled "SHEET GLASS FORMING DEVICE";
- 3) Provisional Application No. 60/318,726, filed Sep. 12, 2001, entitled "SHEET GLASS FORMING APPARATUS";
- 4) Provisional Application No. 60/318,808, filed Sep. 13, 2001, entitled "SHEET GLASS FORMING APPARATUS";
- 5) Provisional Application No. 60/345,464, filed Jan. 3, 2002, entitled "SHEET GLASS FORMING APPARATUS"; and
- 6) Provisional Application No. 60/345,465, filed Jan. 3, 2002, entitled "SHEET GLASS FORMING APPARATUS".

The benefit under 35 USC §119(e) of the U.S. provisional applications is hereby claimed, and the aforementioned applications are hereby incorporated herein by reference.

This application claims an invention related to U.S. application Ser. No. 09/851,627, filed May 9, 2001, entitled "SHEET GLASS FORMING APPARATUS". The aforementioned application is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention pertains generally to the manufacture of glass sheets, and, more particularly, to glass sheets formed from an overflow process.

2. Description of the Related Art

The glass that is used for semiconductor powered display applications, and particularly for TFT/LCD display devices that are widely used for computer displays, must have very high surface quality to allow the successful application of semiconductor type material. Sheet glass made using the apparatus of U.S. Pat. No. 3,338,696, assigned to Corning, Inc., makes the highest quality glass as formed and does not require post-processing. The Corning patent makes glass by a manufacturing process termed: "The Overflow Process". Glass made using other processes requires grinding and/or polishing and thus does not have as fine a surface finish. The glass sheet must also conform to stringent thickness variation and warp specifications. The fine surface finish is formed from virgin glass primarily from the center of the glass stream. This glass has not been in contact with foreign surfaces since the stirring operation.

The teachings of U.S. Pat. No. 3,338,696 are still the state of the art as practiced today. However, the apparatus has limitations.

A major drawback of the apparatus of "The Overflow Process" is that, even though it makes excellent glass over most of the surface, the surface of the glass sheet nearest the inlet is composed of glass that has flowed in proximity to the feeding pipe surfaces and therefore is subject to lower quality.

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Another drawback of the apparatus of "The Overflow Process" is that, even though it makes excellent glass during stable operating conditions, it recovers from transient conditions very slowly. This is caused in part by quiescent zones of glass flow in the pipes conducting the glass from the stirring device to the apparatus when these pipes are designed using traditional practice. During unintended process transient these quiescent zones slowly bleed glass of a previous material composition into the main process stream of glass causing defects. These defects eventually subside when the process stabilizes; however, there is a period of time where the quality of the glass sheet is substandard.

Yet another drawback of the apparatus of "The Overflow Process" is the limited means for controlling the thickness of the formed sheet. The selective cooling of the glass with respect to width as the sheet is formed is not provided in current practice.

The thickness control system of U.S. Pat. No. 3,682,609 can compensate for small thickness errors, but it can only redistribute the glass over distances on the order of 5-10 cm.

Another drawback of the apparatus of "The Overflow Process" is that the forming apparatus deforms during a manufacturing campaign in a manner such that the glass sheet no longer meets the thickness specification. This is a primary cause for premature termination of the production run.

A further drawback of the apparatus of "The Overflow Process" is that surface tension and body forces have a major effect on the molten glass flow down the external sides of the forming apparatus causing the sheet to be narrower than the forming apparatus and the edges of the formed sheet to have thick beads.

U.S. Pat. No. 3,451,798 provides for edge directors which endeavor to compensate for the surface tension effects but are in reality a correction for problems created by restricting the forming apparatus cross-section to a single profile on its external surface.

Another drawback of the prior art is that the glass sheet is not inherently flat when drawn from the forming apparatus.

Yet another drawback of the apparatus of "The Overflow Process" is that the drawing of the sheet from the bottom of the apparatus has a propensity to have a cyclic variation in sheet thickness. This cyclic thickness variation is a strong function of uncontrolled air currents, which tend to become more prevalent as the equipment ages during a production campaign. As the apparatus ages, air leaks develop through cracks in material and assorted openings caused by differential expansion.

Therefore, there is a need in the art for an apparatus which overcomes the shortcomings of the prior art.

SUMMARY OF THE INVENTION

In a preferred embodiment of the present invention, all the glass that forms the surface of the useful area of the sheet is virgin glass, which is not contaminated by flow in proximity to a refractory or refractory metal surface after the stirring operation. In addition, this embodiment significantly reduce inhomogeneities in the glass that forms the sheet by relocating or eliminating the regions of quiescent flow in the piping between the stirring device and the sheet glass forming apparatus.

In another preferred embodiment, this invention introduces a precise thermal control system to redistribute the flow of molten glass at the weirs which is the most critical area of the forming process. This thermal control effectively

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counteracts the degradation of the sheet forming apparatus which inevitably occurs during a production campaign.

In yet another preferred embodiment, the invention introduces a counteracting force to these stresses on the trough in a manner such that the thermal creep which inevitably occurs has a minimum impact on the glass flow characteristics of the forming trough. This embodiment is designed such that this counteracting force is maintained through an extended period of the production campaign. Thus, sheet glass may be manufactured for a longer time with the same forming trough.

Another preferred embodiment creates a variable external cross-section which alters the direction and magnitude of the surface tension and body force stresses and thus, reduces the adverse influence of surface tension and body forces on sheet width.

In an alternative preferred embodiment, the glass is preferentially cooled across its width to create forming stresses during solidification, which ensure that the glass sheet drawn is inherently flat.

In a further preferred embodiment, this invention adjusts the internal pressure in each of the major components of the forming apparatus such that the pressure difference across any leakage path to the forming zone is essentially zero. Therefore, air leakage in the apparatus is minimized even though the cracks and openings exist during initial operation and develop during manufacturing.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates the principle parts of "The Overflow Process" glass sheet manufacturing system.

FIG. 2A shows a side view of "The Overflow Process" as known in the prior art.

FIG. 2B shows a cross-section of the glass flow in the downcomer pipe across lines B—B of FIG. 2A.

FIG. 2C shows a cross-section across lines C—C of FIG. 2A, where the glass flow in the downcomer pipe appears in the sheet for "The Overflow Process".

FIG. 3A shows a side view of a surface flow distribution device in a preferred embodiment of the present invention.

FIG. 3B shows a top view of a surface flow distribution device in a preferred embodiment of the present invention.

FIG. 4A shows a side view of a submerged flow distribution device in a preferred embodiment of the present invention.

FIG. 4B shows a top view of a submerged flow distribution device in a preferred embodiment of the present invention.

FIG. 5A shows a side view of "The Overflow Process" in an embodiment of the present invention.

FIG. 5B shows the glass flow in the downcomer pipe across lines B—B of FIG. 5A when a flow distribution device is used.

FIG. 5C shows a cross-section across lines C—C of FIG. 5A, where the glass flow in the downcomer pipe appears in the sheet when a flow distribution device is used.

FIG. 6 shows a bowl with an inclined axis which diffuses the quiescent flow zone at the bowl nose in a preferred embodiment of the present invention.

FIG. 7A shows the top view of a bowl with side inflow which relocates the quiescent flow zone from the bowl nose to the bowl side in a preferred embodiment of the present invention.

FIG. 7B shows a side view of FIG. 7A.

FIG. 7C shows the top view of a bowl with side inflow which relocates the quiescent flow zone from the bowl nose

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to a location approximately 45 degrees to the side with respect to the centerline of the forming apparatus in a preferred embodiment of the present invention.

FIG. 7D shows a side view of FIG. 7C.

FIG. 8 illustrates a bowl in "The Overflow Process" as known in the prior art.

FIG. 9A shows a downcomer pipe feeding the forming apparatus inlet with minimum quiescent flow in a preferred embodiment of the present invention.

FIG. 9B shows a top view of FIG. 9A.

FIG. 9C shows a detail of the downcomer pipe to trough inlet pipe connection showing the glass flow pattern in a preferred embodiment of the present invention.

FIG. 10A shows the flow between the downcomer pipe and the forming apparatus inlet in "The Overflow Process" as known in the prior art.

FIG. 10B shows a top view of FIG. 10A.

FIG. 10C shows a detail of the downcomer pipe to trough inlet pipe connection showing the glass flow pattern as known in the prior art.

FIG. 11A shows the principle parts of a typical "Overflow Process" manufacturing system.

FIG. 11B shows a section of FIG. 11A.

FIG. 12A illustrates a side view of the glass flowing through the forming trough.

FIG. 12B shows a section through the center of the forming trough of FIG. 12A showing the cooling zones.

FIG. 13A shows a revised single heating chamber muffle design in a preferred embodiment of the present invention.

FIG. 13B shows a section of FIG. 13A.

FIG. 14A shows air cooling tubes to effect localized cooling to the molten glass as it passes over the weirs in a preferred embodiment of the invention.

FIG. 14B shows a section of FIG. 14A.

FIG. 15A shows a muffle with multiple heating chambers in a preferred embodiment of the invention.

FIG. 15B shows a section of FIG. 15A.

FIG. 16A shows radiant coolers which effect localized cooling to the molten glass as it passes over the weirs in a preferred embodiment of the invention.

FIG. 16B shows a section of FIG. 16A.

FIG. 17A illustrates how the prior art trough design deforms as a result of thermal creep.

FIG. 17B shows another view of FIG. 17A.

FIG. 18A shows the forming trough support system as known in the prior art.

FIG. 18B shows another view of FIG. 18A.

FIG. 18C shows, another view of FIG. 18A.

FIG. 18D shows another view of FIG. 18A.

FIG. 19A shows single shaped compression blocks on each end of the trough in a preferred embodiment of the present invention.

FIG. 19B shows another view of FIG. 19A.

FIG. 19C shows another view of FIG. 19A.

FIG. 19D shows another view of FIG. 19A.

FIG. 20A shows a single shaped compression block on one end of the trough and multiple shaped compression blocks on the other end in a preferred embodiment of the present invention.

FIG. 20B shows another view of FIG. 20A.

FIG. 20C shows another view of FIG. 20A.

FIG. 20D shows another view of FIG. 20A.

FIG. 21A shows a trough design as known in the prior art.

FIG. 21B shows a top view of FIG. 21A.

FIG. 21C shows a cross-section of the trough design shown in FIG. 21A across lines C—C.

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FIG. 21D shows a cross-section of the trough design shown in FIG. 21A across lines D—D.

FIG. 21B shows a cross-section of the trough design shown in FIG. 21A across lines E—E.

FIG. 21F shows a cross-section of the trough design shown in FIG. 21A across lines F—F.

FIG. 21G shows a cross-section of the trough design shown in FIG. 21A across lines G—G.

FIG. 22A shows a reduced inverted slope at each end of the trough in a preferred embodiment of the present invention.

FIG. 22B shows a top view of FIG. 22A.

FIG. 22C shows a cross-section of the trough design shown in FIG. 22A across lines C—C.

FIG. 22D shows a cross-section of the trough design shown in FIG. 22A across lines D—D.

FIG. 22E shows a cross-section of the trough design shown in FIG. 22A across lines E—E.

FIG. 22F shows a cross-section of the trough design shown in FIG. 22A across lines F—F.

FIG. 22G shows a cross-section of the trough design shown in FIG. 22A across lines G—G.

FIG. 23A shows an alternate embodiment of the present invention with further modified ends.

FIG. 23B shows a top view of FIG. 23A.

FIG. 23C shows a cross-section of the trough design shown in FIG. 23A across lines C—C.

FIG. 23D shows a cross-section of the trough design shown in FIG. 23A across lines D—D.

FIG. 23E shows a cross-section of the trough design shown in FIG. 23A across lines E—E.

FIG. 23F shows a cross-section of the trough design shown in FIG. 23A across lines F—F.

FIG. 23G shows a cross-section of the trough design shown in FIG. 23A across lines G—G.

FIG. 24A shows an alternate embodiment of the present invention with the potential for increased structural stiffness.

FIG. 24B shows a top view of FIG. 24A.

FIG. 24C shows a cross-section of the trough design shown in FIG. 24A across lines C—C.

FIG. 24D shows a cross-section of the trough design shown in FIG. 24A across lines D—D.

FIG. 24E shows a cross-section of the trough design shown in FIG. 24A across lines E—E.

FIG. 24F shows a cross-section of the trough design shown in FIG. 24A across lines F—F.

FIG. 24G shows a cross-section of the trough design shown in FIG. 24A across lines G—G.

FIG. 25A shows a forming trough with a convex upward forming root which solidifies the center glass before the edge glass in a preferred embodiment of the present invention.

FIG. 25B shows another view of FIG. 25A.

FIG. 25C shows another view of FIG. 25A.

FIG. 25D shows another view of FIG. 25A.

FIG. 26A shows a forming trough with a convex downward forming root which solidifies the edge glass before the center glass in a preferred embodiment of the present invention.

FIG. 26B shows another view of FIG. 26A.

FIG. 26C shows another view of FIG. 26A.

FIG. 26D shows another view of FIG. 26A.

FIG. 27A shows a forming trough with a complexly shaped forming root to solidify the glass in a unique manner over its width in a preferred embodiment of the present invention.

FIG. 27B shows another view of FIG. 27A.

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FIG. 27C shows another view of FIG. 27A.

FIG. 27D shows another view of FIG. 27A.

FIG. 28A illustrates the cooling process in "The Overflow Process" glass sheet forming system as known in the prior art.

FIG. 28B shows a section of FIG. 28A.

FIG. 29A shows how the pressure in the muffle zone may be controlled to minimize leakage in a preferred embodiment of the present invention.

FIG. 29B shows a section of FIG. 29A.

FIG. 30A shows how the pressure in the muffle door zone may be controlled to minimize leakage in a preferred embodiment of the present invention.

FIG. 30B shows a section of FIG. 30A.

FIG. 31A shows how the pressure in the transition zone may be controlled to minimize leakage in a preferred embodiment of the present invention.

FIG. 31B shows a section of FIG. 31A.

FIG. 32A shows how the pressure in the annealer and pulling machine zone may be controlled to minimize leakage in a preferred embodiment of the present invention.

FIG. 32B shows a section of FIG. 32A.

DETAILED DESCRIPTION OF THE INVENTION

The flow dynamics of this invention are such that the outside surfaces of the glass sheet are formed from thoroughly mixed virgin glass that comes from the center of the glass stream flowing into the forming apparatus and thus has not contacted a refractory or refractory metal surface. This produces the highest possible surface quality. This pristine surface is essential for the manufacture of LCD/TFT semiconductor display devices. In addition, the flow dynamics in all embodiments of this invention are such that the flow rate of molten glass to the forming wedge at the bottom of the forming trough is substantially uniform over its width.

Referring to FIGS. 1, 11A and 11B, a typical "Overflow Process" manufacturing system (1) is shown. The glass (10) from the melting furnace (2) and forehearth (3), which must be of substantially uniform temperature and chemical composition, feeds a stirring device (4). The stirring device (4) thoroughly homogenizes the glass. The glass (10) is then conducted through a bowl inlet pipe (5), into a bowl (6), and down into the downcomer pipe (7), through the joint (14) between the downcomer pipe (7) and the forming apparatus inlet pipe (8), to the inlet of the overflow trough (9). While flowing from the stirring device (4) to the trough (9), the glass (10), especially that which forms the sheet surface, must remain homogeneous. The normal purpose of the bowl (6) is to alter the flow direction from horizontal to vertical and to provide, a means for stopping the flow of glass (10). A needle (13) is provided to stop glass flow. The normal function of the joint (14) between the downcomer pipe (7) and the trough inlet pipe (8) is to allow for removal of the sheet glass forming apparatus for service as well as a means of adjustment of the process equipment.

The molten glass (10) from the melting furnace and forehearth, which must be of substantially uniform temperature and chemical composition, enters the forming apparatus through the inlet pipe (8) to the sheet forming trough (9). The inlet pipe (8) is preferably shaped to control the velocity distribution of the incoming molten glass flow. The glass sheet forming apparatus, which is described in detail in both U.S. Pat. No. 3,338,696 and patent application Ser. No. 09/851,627, herein incorporated by reference, is a wedge shaped forming device (9). Straight sloped weirs (115),

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substantially parallel with the pointed edge of the wedge (root) (116), form each side of the trough. The bottom of the trough (117) and sides of the trough (118) are contoured in a manner to provide even distribution of glass to the top of each side weir (115). The glass then flows over the top of each side weir (115), down each side of the wedge shaped forming device (9), and joins at the pointed edge of the root (116), to form a sheet of molten glass (11). The sheet of molten glass (11) is then cooled as it is pulled off the root (116) by pulling rollers (111) to form a solid glass sheet (12) of substantially uniform thickness. Edge rollers (110) may also be used to draw the molten glass sheet (11). In the prior art, the forming trough (9) is encased within a muffle whose purpose is to control the temperature of the forming trough (9) and the molten glass (10). It is normal practice to maintain a uniform temperature in the muffle chamber (113) surrounding the forming trough (9). Cooling the glass as it transitions from the molten state to the solid state must be carefully controlled. This cooling process starts on the lower part of the forming apparatus (9) just above the root (116), and continues as the molten glass sheet passes through the muffle door zone (114). The molten glass is substantially solidified by the time it reaches the pulling rollers (111). The molten glass forms a solid glass sheet (12) of substantially uniform thickness.

Altering Glass Flow Distribution

Referring also to FIGS. 2 through 10, a preferred embodiment of the present invention alters the flow path at the inlet of the sheet glass forming apparatus to improve surface quality. It also facilitates more uniform flow of glass through the piping that conducts the glass from the stirring device to the sheet glass forming apparatus.

U.S. Pat. No. 3,338,696 considers only the glass flow within the forming trough. U.S. Pat. No. 3,338,696 also claims that the entire sheet surface is formed from virgin glass, which has not been adversely effected by contact with a foreign surface. This is not entirely correct as the sheet formed on the inlet end of the trough has flowed on the piping system front surface. A flow distribution device is added at the trough inlet in this invention to ensure that all of the useable sheet surface is formed from virgin glass. The piping system between the glass stirring device and the glass sheet forming apparatus is modified from traditional practice in the bowl and at the connection between the downcomer pipe and the forming apparatus inlet pipe. The flow through the bowl is altered, either eliminating or relocating the quiescent flow zone that normally forms at the front top surface of the bowl. The downcomer pipe is not submerged in the forming apparatus inlet pipe glass thus eliminating the quiescent flow zone between the pipes.

FIGS. 2A through 2C illustrate where the glass (10) flowing in the downcomer feed pipe (7) ends up in the formed glass sheet in the prior art "Overflow Process". The glass flow in proximity to the sides (21) of the downcomer pipe (7) ends up in the center of the drawn sheet. The flow (23) in proximity to the front surface of the downcomer pipe (7) is distributed over the entire glass surface, however, it is most concentrated on the approximate one third of the sheet at the inlet end. This surface glass (23) is subject to disruption by the downcomer pipe surface and by the glass in the quiescent zones in the bowl (6) and at the downcomer pipe (7) to inlet pipe (8) connection (14). The surface of the remaining substantially two thirds of the sheet is formed from virgin interior glass (22). Two other portions of the glass flow (24) which are symmetrically offset from the front surface at an angle of approximately 45 degrees end up

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forming the near end unusable edge section (25) at the inlet end of the sheet. Another portion (26) centered at the back surface at an angle of approximately 180 degrees proceeds to the far end unusable edge section (27).

FIGS. 3A and 3B show an embodiment of the glass sheet forming apparatus (31) with an inflow pipe (8), a flow distribution device (32) (which is a subject of this invention) located at the trough inlet surface, and the glass sheet forming apparatus body (9). The flow distribution device (32) interrupts the glass surface flow and diverts it to the surface in the edge of the sheet. Glass from the center of the downcomer pipe flow stream then comes to the surface of the forming trough to form the surface of the useable portion of the glass sheet (11). Note that ten to twenty percent of the sheet at each edge is, normally unusable for various reasons.

FIGS. 4A and 4B show an alternative embodiment of the glass sheet forming apparatus (41), which performs the same function as the embodiment in FIG. 3 except that the surface flow distribution device (42) is located under the surface of the glass (10) and redistributes the surface flow in a more subtle but equally effective manner. The glass flow (10) that forms the unusable inlet edge of the sheet, flows through the center slot (43) in the flow distribution device (42). The glass (which flows through this center slot) is the glass that has been in proximity to the front surface of the downcomer pipe. Glass from the center of the downcomer pipe then flows to the trough surface to form the surface of the useable portion of the sheet (11). Other glass that flows in proximity to the surface of the downcomer pipe remains submerged.

FIGS. 5A through 5C illustrate where the glass (10) flowing in the downcomer feed pipe (7) ends up in the formed glass sheet for the inventions described in FIGS. 3 and 4. The glass flow to the center of the sheet (21) is virtually identical to that in the prior art. However, the flow (52) which forms the outside surface of the formed glass sheet does not flow in proximity to the front surface of the downcomer pipe (7). The two portions of the glass flow (24) which are symmetrically offset from the front surface at an angle of approximately 45 degrees and which end up forming the unusable edge section (25) at the inlet end of the sheet are substantially unaffected, as is the glass flow (26) which ends up in the unusable edge section (27).

FIG. 6 is an embodiment that shows the axis of the bowl (66) inclined at an angle such that the main process stream passes through the front of the bowl. This active flow (60) entrains the surface glass (61), overcoming the surface tension forces that would normally create a quiescent zone of glass flow located at the bowl nose (FIG. 8). A needle (13) is present to stop glass flow.

FIGS. 7A through 7D show an embodiment of the present invention where a crossways motion of the glass in the bowl (76) is facilitated by feeding the glass in the pipe coming from the stirring device to the bowl (75), into the side of the bowl (76) at an angle (74) with respect to the centerline (73) of the forming apparatus (9). This effectively changes the flow pattern (70) in the bowl such that the quiescent zone normally located at the bowl nose (81, FIG. 8) is moved to the side of the bowl (71). Referring back to FIGS. 2A-2C and 5A-5C, depending on the angle (74) of the flow in the bowl with respect to the centerline (73) of the forming apparatus (9), the glass from the quiescent zone (71) ends up in either the unusable portion of the edges (25), (27) or is submerged in the center of the glass sheet (21) instead of on the surface of the glass sheet (23). The glass free surface (72) in the bowl is also shown.

FIG. 8 illustrates the prior art with a bowl (6) which shows the quiescent zone (81) of glass that is located at the front of

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the bowl (6). This glass is kept in place by a combination of low process stream flow (80) at the front of the bowl and surface tension.

FIGS. 9A through 9C show an embodiment of the present invention where the bottom end (94) of the downcomer pipe (97) is located substantially above the glass free surface (90) in the forming apparatus inlet pipe (98). The bottom end of the downcomer pipe (97) and the forming apparatus inlet (98) also have a specific size and shape, (95) and (92), respectively. The vertical distance (93) and the size and shape (92) of the forming apparatus inlet (98) is specifically designed to minimize any zone of quiescent or vortex flow in the glass flow path (91). Thus, the molten glass (10) forms a more homogenous sheet (11). This design is determined by solution of the fluid flow equations (Navier-Stokes Equations) and by experimental tests.

FIGS. 10A through 10C show a downcomer pipe (7) submerged in the molten glass surface (100) in the forming apparatus inlet pipe (8) as known in the prior art. There is a quiescent zone (101) between the two pipes (7) and (8). The glass flow path (103) produces an annular vortex (102) of glass between the downcomer pipe (7) and the trough inlet pipe (8). The vortex exchanges little material with the main process stream except during flow transients at which time it produces defects in the glass sheet.

Reducing Degradation of Sheet Glass Forming Apparatus

Referring now to FIGS. 12 through 16, another embodiment of the present invention controls the flow distribution of glass on the forming apparatus in a manner such that the degradation of the production apparatus and the deformation of the forming trough that results from thermal creep is compensated by thermal control of the glass flow distribution.

U.S. Pat. No. 3,338,696 relies on a specifically shaped forming trough to distribute the glass in a manner to form a sheet of uniform thickness. The basic shape of this forming trough is described in detail in U.S. Pat. No. 3,338,696. The sheet glass forming process is conducted at elevated temperatures, typically between 1000° C. and 1350° C. At these temperatures, the refractory materials used for construction of the forming trough exhibit a property called thermal creep, which is deformation of the material caused by applied stress. Thus, the trough deforms under the stress caused by its own weight and the stress caused by the hydrostatic pressure of the glass in the trough.

The materials used in the construction of the other parts of the forming apparatus also degrade (warp, crack, change thermal properties, etc.) in an indeterminate way, which has an adverse effect on thickness distribution. The thickness control system of U.S. Pat. No. 3,682,609 can compensate for small thickness errors, but it can only redistribute the glass over distances on the order of 5–10 cm. To significantly effect thickness distribution over the entire width of the glass sheet, the flow of the molten glass over the weirs must be controlled.

This embodiment of the invention solves this problem by introducing a precise thermal control system to redistribute the flow of molten glass at the weirs, which is the most critical area of the forming process. This thermal control effectively counteracts the degradation of the sheet forming apparatus which inevitably occurs during a production campaign.

FIG. 12A shows the side view of the forming trough (9) with arrows showing the flow of molten glass (10) through the forming trough (9) to the side weirs (115). FIG. 12B shows a section through the center of the forming trough (9)

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which shows the different zones for the control of molten glass (10) as it flows through the forming apparatus. Zone (121) is the flow from the inlet end of the trough to the far end, zone (122) is the flow over the weirs, zone (123) is the flow down the outside of the forming trough, and zone (124) is the molten glass (11) being pulled off the root (116) and cooling into a solid sheet (12). The effect on the solid glass sheet (12) thickness caused by heating or cooling the molten glass (10) as it passes through each zone is different. Adding energy to (raising the temperature of) or removing energy from the molten glass (10) as it flows from the inlet end to the far end of the forming trough (9) in zone (121) produces concave or convex sheet thickness profiles respectively. The period of the thickness profile changes effected in zone (121) is on the order of the length of the trough.

Changes to the energy flux to the molten glass (10) as it flows over the weirs (115) in zone (122) has a powerful effect on the resultant solid glass sheet thickness distribution. Localized cooling of the glass in zone (122) effectively produces a dam, which has a large effect on glass flow. This is an extremely sensitive zone, and any control strategy other than isothermal must be carefully designed. Zone (123) is important to return the glass to a uniform temperature distribution, substantially linear in the longitudinal direction, in order that the drawing process at the root (116) is consistent. Differential cooling in zone (124) is the object of U.S. Pat. No. 3,682,609 and is effective in making small thickness distribution changes. Cooling at given longitudinal location affects the thickness at that location in one direction and conversely to the glass on each side of the location. The effect is longitudinal redistribution of the glass over a distance on the order of centimeters.

FIGS. 13A and 13B show an embodiment of this invention whereby the top and sides of the muffle (132) are shaped more closely to the outside surface of the molten glass (10) that is flowing in and on the forming trough (9). The muffle (132) is heated by heating elements in heating chamber (131). The primary heat transfer medium in the muffle chamber (113) is radiation. By designing the muffle (132) to conform closely to the outside shape of the molten glass (10), energy may be directed to targeted areas of the molten glass (10), thereby effecting greater control of temperature distribution. The heating elements in the heating chamber (131) have adequate power to balance the energy flux to the forming trough (9) and thus create suitable temperature conditions.

FIGS. 14A and 14B show an embodiment of this invention which effects localized cooling of the molten glass (10) as it passes over the weirs (115) in zone (122). The muffle (132) configuration of FIGS. 13A and 13B is used. Air cooling tubes (142), similar in function to those air cooling tubes (141), which are described in U.S. Pat. No. 3,682,609, are directed at the heating chamber side of the muffle (143) just above the molten glass (10) flowing over the weirs (115). Localized cooling of the glass in this location effectively produces a localized dam, which has, a significant effect on the thickness distribution of the solid glass sheet.

FIGS. 15A and 15B show an embodiment of this invention whereby the multi-chamber muffle (156) is designed with separate heating chambers (151–155) to control the temperature of the molten glass (10) as it passes through the various individual zones of the forming process. These zones (121–124) are described in FIGS. 12A and 12B. The multi-chamber muffle (156) has five heating chambers (151–155). Heating chamber (153), located over the top of the forming trough (9), effects the flow of glass from the inlet end to the far end of the forming trough (9), (zone

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(121)). The heating chambers (152) and (154) over the top of the weirs (115) effect the flow over the weirs (115) (zone (122)), and the heating chambers (151) and (155) on each side of the trough (9) are used to balance the temperature longitudinally (zone (123)). All the heating chambers (151-155) have heating elements with adequate power to balance the energy flux to the forming trough (9) and thus create suitable temperature conditions.

FIGS. 16A and 16B show an embodiment of this invention which affects localized cooling to the molten glass (10) as it passes over the weirs (115). This is zone (122) shown in FIG. 12B. The multi-chamber muffle (156) configuration of FIGS. 15A and 15B is used. Specially designed radiant coolers (161), installed in heating chambers (152) and (154), have the ability to selectively cool the heating chamber side of the muffle surface (162) opposite the weirs (115). The radiant cooler has multiple adjustments (164) such that the temperature of its bottom surface can be varied in the longitudinal direction. The distribution of the heat transfer between the radiant cooler (161) and the muffle surface (162) is a function of the distance (163). By varying the distance (163) between the cooling device (161) and the muffle surface (162), the cooling effect may be attenuated to adjust sensitivity. Although it is not illustrated, the cooling devices (161) are replaceable during operation. The radiant coolers (161) could alternately be inserted from the side instead of the top with a suitable change in the design of the heating chambers (152), (153) and (154).

In an alternative embodiment, the air cooling tubes (142) of FIG. 14A and 14B could be used with the muffle (156) design of FIGS. 15A and 15B, and the radiant coolers (161) of FIGS. 16A and 16B could be used with the muffle (132) configuration of FIGS. 13A and 13B.

Reducing Thickness Variations in the Glass Sheet

Referring to FIGS. 17 through 20, another embodiment of the present invention supports and stresses the forming apparatus in a manner such that the deformation that results from thermal creep has a minimum effect on the thickness variation of the glass sheet. This embodiment introduces a counteracting force to these stresses on the trough in a manner such that the thermal creep which inevitably occurs has a minimum impact on the glass flow characteristics of the forming trough. The invention is designed such that this counteracting force is maintained through an extended period of the production campaign. Thus, sheet glass may be manufactured for a longer time with the same forming trough.

The refractory materials from which the forming trough and its support structure are made have high strength in compression and low strength in tension. Like most structural materials, they also change shape when stressed at high temperature. This embodiment was developed due to the material characteristics and how these characteristics affect the manufacturing process.

There are two fundamental concepts in this embodiment of the invention. First, applying a force and/or moments to the ends, of the trough counteracts stress caused by the forces of gravity, thus minimizing the effect on molten glass flow caused by thermal creep. Second, the invention uses compression members shaped such that thermal creep, to which the compression members are also subject, does not substantially alter the application of said force and/or moment.

FIGS. 17A and 17B illustrate the typical effects of thermal creep on the shape of the trough. FIG. 17A shows that the forming trough (9) sags in the middle such that the top of the

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weirs (115), and the root (116) are now curved (171) and the trough bottom (117) has a change in curvature (171). This curvature (171) causes the molten glass (10) to no longer flow with constant thickness (172) over the weirs (115). This curvature (171) allows more glass to flow over the middle of the weirs resulting in an uneven sheet thickness distribution. FIG. 17B shows how the hydrostatic force (174) from the molten glass (10) in the forming trough (9) forces the weirs (115) to move apart at the top. This allows more glass to flow to the middle of the forming trough (9) making the thickness in the middle even greater.

FIGS. 18A through 18D show a sheet glass forming apparatus (180) as known in the prior art. The forming trough (9) is supported by an inlet end supporting block (181) and a far end supporting block (182). The forming trough (9) is the equivalent of a beam, which is subject to a bending stress from its own weight, from the weight of the glass in and on the trough, and from drawing forces. Because of the low tensile strength of the trough material, a compressive force (183) is applied to the lower half of the forming trough (9) to force the material at the root (116) of the forming trough (9) into compression. Typically the inlet end support block (181) is restrained in the longitudinal (horizontal) direction and the compression force (183) is applied to the far end support block (182). The prior art considers only preventing tension at the root (116) of the forming trough (9), and then only the stress at start-up. Little consideration is made for the effects on stress of the thermal creep of the forming trough (9) and its support blocks (181) and (182).

FIGS. 19A through 19D show an embodiment of a sheet glass forming apparatus (190) that has shaped end support blocks (191) and (192). The inlet end shaped support block (191) is restrained in the longitudinal direction. A compression force (193) is applied to the far end shaped support block (192). The shape of the support block is designed in a manner to produce a force distribution in the forming trough (9) to substantially counteract the effect of the weight of the forming trough (9) and the molten glass (10). The applied force (193) is such that all material in the forming trough (9) is under substantially equal compression stress in the longitudinal direction. This stress causes the thermal creep to occur primarily in the longitudinal direction with little of the sagging shown in FIG. 17A. The forming trough (9) gets shorter due to the equal compressive stress in the longitudinal direction. The shaped support blocks are also subject to thermal creep. The cross section of the shaped support block is the same over substantially its entire length with equal compressive stress across its section. Thus as the shaped support block deforms from thermal creep, it continues to apply substantially the same force distribution to the forming trough (9).

FIGS. 20A through 20D show an embodiment of a sheet glass forming apparatus (200) that has four shaped end support blocks (201), (202), (204), and (205). The inlet end has three shaped support blocks (201), (204), and (205), all of which have longitudinal compression forces (206), (207), and (208) applied. A compression force (203) is applied to the far end shaped support block (202). The shape and loading of the support blocks (202) and (203) are designed to the same criteria as support blocks (191) and (192) in FIGS. 19A-19D. The two upper shaped support blocks (204) and (205) are attached to the inlet end of the weirs and are angled such that they exert an additional force on the weirs to counteract the affect of the hydrostatic forces which tend to spread the weirs apart. Although the blocks (204) and

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(205) are shown with an inward angle in the figures, they also could be angled outward without deviating from the spirit of the invention.

In a preferred embodiment, short (10–25% of length) transition zones (not shown) are at the trough ends of the shaped support blocks. In these transition zones, the cross-section of the shaped support block will change from that of the shaped support block to a shape that will suitably apply the design load to the trough block.

Effects of Surface Tension on the Sheet

In an alternative embodiment of the invention, the width and the angle of the inverted slope of the forming wedge may be changed to alter the effect of surface tension and body forces on the narrowing of the sheet. In addition, the width and the inverted slope angle may be increased to make the structure stiffer and thus more resistant to thermal creep.

FIGS. 21A through 21G show the prior art shape of the forming trough. The cross-section of the wedge shaped portion, FIGS. 21C through 21G, is uniform over the entire useable length of the trough. The width of the trough (211) and the angle of the inverted slope (210) are identical at each section. As the molten glass (10) flows down the vertical portion (211) of the forming wedge (9), the surface tension and body forces have a minimal effect on the sheet width (212), whereas, when the molten glass (10) flows vertically down the inverted slope portion (210) of the forming wedge, the surface tension and body forces act to make the sheet narrower (213).

FIGS. 22A through 22G show an identical width of the trough (211) over its entire length, whereas the angle of the inverted slope (210) is the same in the center of the trough (FIGS. 21D–21F) and the angle of the inverted slope (220) at each end is reduced. This reduced inverted slope (220) has a counterbalancing effect on the surface tension and body force stresses and thus reduces the narrowing of the sheet (223).

FIGS. 23A through 23G show the width of the trough (211) and the angle of the inverted slope (210) being the same in the center of the trough (FIGS. 21D through 21F and FIGS. 22D through 22F), whereas, the width of the trough (231) and the angle of the inverted slope (230) at each end are reduced. This reduced width (231) and inverted slope (230) have a counterbalancing effect on the surface tension and body force stresses over the effect of FIGS. 22A through 22G and thus further reduces the narrowing of the sheet (233).

FIGS. 24A through 24G show another embodiment of this invention, wherein the width of the trough (211) and (231) and the angle of the inverted slope (210) and (230) are the same as in the embodiment of FIGS. 23A through 23G except that the angle of the inverted slope (240) at the center of the trough, FIG. 24E is substantially greater than the other inverted slopes (210) and (230). This greater angle increases the section modulus of the structure making it stiffer and thus less prone to thermal creep. Keeping the configuration of the ends the same as FIGS. 23A through 23G has substantially the same effect on the surface tension and body force stresses as FIGS. 23A through 23G and thus has little effect on the narrowing of the sheet (243).

Producing a Flat Sheet

U.S. Pat. No. 3,338,696 considers only the glass flow in the forming trough and assumes that the drawn glass from the bottom of the forming trough will be of uniform thickness and flatness because of the uniform thickness of the flow of glass to the critical point of solidification. In practice, glass must be preferentially cooled across its width to create

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forming stresses during solidification that create a flat sheet. The present invention alters the forming stresses and cooling distribution such that the formed sheet is inherently flat.

FIGS. 25A through 25D show an embodiment of this invention where the shape of the bottom of the forming wedge (116) is not straight but is formed convex upward (250). This causes the glass that is drawn from the center of the forming wedge (251) to cool faster than the glass drawn from each edge (252) of the forming wedge. The strategy is to impose stresses on the partially solidified glass (251) in the center of the sheet to cause the sheet to be flatter, having less warp.

FIGS. 26A through 26D show another embodiment of this invention where the shape of the bottom of the forming wedge (116) is not straight but is formed convex downward (260). This causes the glass that is drawn from the center of the forming wedge (261) to cool slower than that drawn from each edge (262) of the forming wedge. The strategy is to hold the more solidified edges (262) apart, primarily with the edge rollers (110), such that stresses caused by the shrinkage of the partially solidified glass (261) in the center of the sheet cause the sheet to be flatter, having less warp.

FIGS. 27A through 27D show an embodiment of this invention where the shape of the bottom of the forming wedge (116) is not straight but has complex shape across its width (270). This causes the glass that is drawn from the forming wedge (9) to have an equivalent cooling profile. The cooling strategy from this configuration would be a combination of that shown in FIGS. 25A through 25D and 26A through 26D.

Reducing Air Leakage

U.S. Pat. No. 3,338,696 relies primarily on careful design and matching of materials to prevent any material cracks and openings. These cracks and openings are the sources of air leakage, for both initial operation and for operation during the course of a manufacturing campaign. This embodiment of the invention provides individual pressure balancing technology such that even if a leakage path exists at start-up or develops during operation, a minimum quantity of air will flow through the leakage paths.

The glass sheet is formed by drawing the glass from the bottom of the overflow forming trough. The molten glass is cooled and is solidified in a carefully controlled manner. The most desirable cooling phenomena is radiation, which cools the glass substantially evenly through its entire thickness. Convective cooling, which cools only the glass surface, is also a factor. The convective cooling must be minimized as it has a destabilizing effect on the drawing process. The observed phenomena is a cyclic variation in sheet thickness as it is drawn. This is termed "pumping" and is a phenomena noted in all glass drawing processes.

The operating temperature of the forming zone of "The Overflow Process" is typically 1250° C. and is at the top of an open bottom chamber, typically 3 meters high, containing an atmosphere of hot air. Because of the approximately 3 meter column of high temperature air, the atmosphere in the zone where the sheet is formed has a pressure higher than the pressure outside of the forming apparatus. Therefore, any crack or opening creates an airflow path whereby air flows into the open bottom of the chamber, up the chamber and out the cracks or openings. This leakage substantially increases the convective cooling in the forming zone and subsequently produces a cyclic variation in the sheet thickness.

For air to flow through an opening there must be a difference in pressure from one side of the opening to the other. This invention involves adjusting the internal pressure

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in each of the major components of the forming apparatus such that the pressure difference across any leakage path to the forming zone is essentially zero. Therefore, if an opening either exists or develops, no air leakage will occur as there is no differential pressure to force airflow.

The air pressure in the internal chambers of the forming system is substantially higher than the ambient pressure in the factory. This is because of the low density of the heated air contained in the forming system. This elevated pressure forces the internal air to leak through any openings or cracks in the membranes which separate the forming zones from the heating and cooling zones. The leakage can be minimized by equalizing the air pressure on each side of any leakage path.

Referring now to FIGS. 28A through 32B, FIGS. 28A and 28B show cooling of the glass as it transitions from the molten state to the solid state. This process must be carefully controlled. This cooling process starts on the lower part of the forming apparatus (9) just above the root (116), in the muffle zone (280), continues as the molten glass sheet (11) passes through the muffle door zone (114), and is substantially solidified by the time it leaves the transition zone (281). The controlled cooling process continues in the annealer and pulling machine zone (282) to relieve internal stress in the solidified glass sheet (12).

Four embodiments for controlling forming chamber pressure differentials are shown in FIGS. 29A through 32B. These are a) adding flow to pressurize, b) restricting outflow, c) flowing to a vacuum, and d) encasement by a pressurizing chamber, respectively. Any of these control methods may be used to control the pressure in either the muffle zone (280), the muffle door zone (114), the transition zone (281), or the annealing and pulling machine zone (282) depending on unique design requirements. The critically important objective, however, is to equalize the pressure on each side of the membrane separating either the factory atmosphere or a heating zone or a cooling zone from the forming chamber. This invention also applies to implementations of "The Overflow Process" where the gas in the forming chamber is a gas other than air, i.e. nitrogen, etc.

More specifically, FIGS. 29A and 29B show an embodiment of the muffle zone (280) which shows air (290), which is preferably preheated, introduced into the muffle heating chamber (131) to make the pressure in the heating chamber (131) equal to that in the adjacent forming chamber (113). The wall (132) separating the two chambers in the muffle is normally constructed of many pieces and is therefore susceptible to random leaks. Equalizing the pressure between the two chambers minimizes the leakage flow.

FIGS. 30A and 30B show an embodiment of the muffle door zone (114), which includes an exit restriction (300) to the flow of air exiting each muffle door (301) to factory ambient pressure. The size of this restriction is varied to regulate the pressure inside the muffle door (302) equal to that in the pressure in the adjacent forming chamber (303). The flow of air into the muffle doors (301) through the cooling tubes (141) would normally be adequate to overcome any leakage paths and thus raise the muffle door internal pressure (302) to that of the adjacent forming chamber pressure (303).

FIGS. 31A and 31B show an embodiment of the transition zone (281), which has the cooling air at elevated pressure (310) entering the cooling chamber (311) and exiting (312) each of the transition coolers (313) into a regulated vacuum source (314). The large volume of air required for cooling in the transition zone would normally raise the pressure in the transition cooling chamber (311) above that of the adjacent

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forming chamber (315). A vacuum source (314) is therefore required to lower the pressure and is adjusted to equalize the pressure in the transition cooling chamber (311) to the pressure in the adjacent forming chamber (315).

FIGS. 32A and 32B show an embodiment of the annealer and pulling machine zone (282), which includes a pair of pressure balancing chambers (320) on each end of the annealer and pulling machine (282). The pressure in the balancing chamber (321) is adjusted to be equal to the pressure in the annealing chamber (322). A chamber at each end was chosen because the bearings and adjustment mechanisms for the pulling rollers (111) are on the ends. Alternate configurations would be one single pressure balancing chamber (320) encasing the entire annealer and pulling machine (282) or a multitude of individual pressure balancing chambers (320) as would be required by particular design considerations.

Accordingly, it is to be understood that the embodiments of the invention herein described are merely illustrative of the application of the principles of the invention. Reference herein to details of the illustrated embodiments is not intended to limit the scope of the claims, which themselves recite those features regarded as essential to the invention.

What is claimed is:

1. An improved apparatus for forming sheet glass, wherein the apparatus includes a trough for receiving molten glass that has sides attached to a wedged shaped sheet forming structure that has downwardly sloping sides converging at the bottom of the wedge such that a glass sheet is formed when molten glass flows over the sides of the trough, down the downwardly sloping sides of the wedged shaped sheet forming structure and meets at the bottom of the wedge, and wherein the improvement comprises a muffle; and at least one heating chamber located adjacent to the muffle on a side opposite the trough, wherein the top and the sides of the muffle are shaped to an outside surface of the molten glass flowing in and on the trough.

2. The improved apparatus of claim 1, wherein the improvement further comprises a plurality of air cooling tubes directed at a heating chamber side of the muffle just above the molten glass, wherein the air cooling tubes vary a temperature in a longitudinal direction.

3. The improved apparatus of claim 1, wherein the improvement further comprises a plurality of radiant coolers installed in the heating chamber just above the molten glass, wherein the radiant coolers vary a temperature in a longitudinal direction.

4. The improved apparatus of claim 1, wherein a structure of the muffle creates five heating chambers comprising:

- a) a heating chamber over a top of the trough;
- b) a heating chamber over a left side of the trough sides;
- c) a heating chamber over a right side of the trough sides;
- d) a heating chamber on a left side of the trough; and
- e) a heating chamber on a right side of the trough.

5. The improved apparatus of claim 1, wherein the improvement further comprises:

- a) at least one inlet end support block located at an inlet end of the trough, wherein the inlet end support block supports the trough; and
- b) at least one far end support block located at an opposite end of the trough as the inlet end support block, wherein the far end support block supports the trough; wherein the inlet end support block and the far end support block are shaped to distribute force in the trough to counteract the effect of the weight of the trough such that an applied force puts all the refractory

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that comprises the trough structure under substantially equal compression stress in a longitudinal direction; such that any deformation of the forming trough that results from thermal creep has a minimal effect on a thickness variation of the glass sheet.

6. The improved apparatus of claim 5, wherein there are three inlet end support blocks, wherein two of the inlet end support blocks are attached to an inlet end of each of the trough sides and angle to exert an additional force on the trough sides to counteract a plurality of hydrostatic forces which spread the trough sides apart.

7. The improved apparatus of claim 5, wherein the improvement further comprises:

c) a shape of each support block such that the support block is uniformly stressed in the longitudinal direction;

wherein the thermal creep of the support block is uniform, thereby maintaining a required force distribution on the trough; and

d) a transition zone in a support block shape of approximately 10-25% of the length of the support blocks to adapt its shape to that of the trough.

8. The improved apparatus of claim 1, wherein an angle of an inverted slope at each end of the trough is less than an angle of an inverted slope at a center of the trough.

9. The improved apparatus of claim 1, wherein a width of the trough at an end of the trough is less than a width of the trough at a center of the trough.

10. The improved apparatus of claim 1, wherein an angle of an inverted slope at a center of the trough is substantially greater than the angle of the inverted slopes not in the center of the trough.

11. The improved apparatus of claim 1, wherein the improvement further comprises a shape of a bottom of the wedge shaped sheet forming structure selected from the group consisting of:

a) convex upward;

b) convex downward; and

c) a wave comprising both convex downward and convex upward portions;

such that a sheet formed from the apparatus is flat.

12. The improved apparatus of claim 11, wherein the shape of the bottom of the wedge shaped sheet forming structure affects a thickness distribution of the glass in the edges of the sheet.

13. An improved apparatus for forming sheet glass, wherein the apparatus includes a trough for receiving molten glass that has sides attached to a wedged shaped sheet forming structure that has downwardly sloping sides converging at the bottom of the wedge such that a glass sheet is formed when molten glass flows over the sides of the trough, down the downwardly sloping sides of the wedged shaped sheet forming structure and meets at the bottom of wedge, and wherein the improvement comprises a variable cross-section of the apparatus; wherein an angle of an inverted slope at each end of the trough is less than an angle of an inverted slope at a center of the trough.

14. The improved apparatus of claim 13, wherein a width of the trough at an end of the trough is less than a width of the trough at a center of the trough.

15. The improved apparatus of claim 13, wherein an angle of an inverted slope at a center of the trough is substantially greater than the angle of the inverted slopes not in the center of the trough.

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16. The improved apparatus of claim 13, wherein the improvement further comprises a shape of a bottom of the wedge shaped sheet forming structure selected from the group consisting of:

a) convex upward;

b) convex downward; and

c) a wave comprising both convex downward and convex upward portions;

such that a sheet formed from the apparatus is flat.

17. The improved apparatus of claim 16, wherein the shape of the bottom of the wedge shaped sheet forming structure affects a thickness distribution of the glass in the edges of the sheet.

18. The apparatus of claim 13, wherein the improvement further comprises a variable width of the structure and angle of the downwardly sloping sides.

19. A molten glass delivery system for use in producing sheet glass by a fusion process comprising: (a) a first conduit which has a first characteristic cross-sectional dimension; and (b) a second conduit which has an exit end and a second characteristic cross-sectional dimension; wherein: (i) the first conduit receives molten glass from the second conduit; (ii) a portion of the first conduit surrounds a portion of the second conduit; and (iii) the first characteristic cross-sectional dimension is larger than the second characteristic cross-sectional dimension so that a free surface of molten glass is formed between the first and second conduits;

wherein the portion of the second conduit which is surrounded by the first conduit is substantially vertically oriented; and

wherein the molten glass between the first and second conduits defines a free surface and the exit end of the second conduit is above said free surface.

20. The system of claim 19, wherein the first and second conduits are positioned relative to one another so that the spatial relationship between the exit end of the second conduit and the free surface of the molten glass results in the formation of a homogeneous glass sheet.

21. The system of claim 19, wherein the first and second conduits are positioned relative to one another to minimize a zone of quiescent or vortex flow in a path of glass flow.

22. The system of claim 19, wherein the apparatus further comprises a flow distribution device located under a surface of the glass and the apparatus reduces a plurality of inhomogeneities in the glass forming the usable portion of the formed sheet.

23. The system of claim 19, wherein the apparatus further comprises a flow of glass into the bowl at an angle of approximately 45 degrees with respect to the centerline of the trough and the apparatus reduces a plurality of inhomogeneities in the glass forming the usable portion of the formed sheet.

24. A method for reducing the sag rate of a forming trough having a longitudinal axis, a middle region, a first end and a second end opposite the first end, said method comprising:

a) supporting the forming trough at the first end with a first end support block and at the second end with a second end support block;

b) restraining the forming trough at a lower portion of the first end; and

c) applying a force to the ends of the trough to counteract stress caused by the forces of gravity, wherein the force causes the thermal creep to occur primarily in the longitudinal direction, Thus minimizing the effect on molten glass flow caused by thermal creep.

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25. The system of claim 24, wherein any deformation of the forming trough that results from thermal creep has a minimal effect on a thickness variation of the glass sheet.

26. An improved apparatus for forming sheet glass, wherein the apparatus includes a trough for receiving molten glass that has sides attached to a wedged shaped sheet forming structure that has downwardly sloping sides converging at the bottom of the wedge such that a glass sheet is formed when molten glass flows over the sides of the trough, down the downwardly sloping sides of the wedged shaped sheet forming structure and meets at the bottom of the wedge, and wherein the improvement comprises a bowl connected to the inflow pipe at an end opposite the trough via a downcomer pipe, wherein the molten glass is fed into the bowl at an angle between 30 degrees and 180 degrees with respect to the axis of the centerline of the trough such that the less desirable glass is not on the surface of the sheet, wherein the apparatus reduces a plurality of inhomogeneities in the glass forming the usable portion of the formed sheet.

27. The improved apparatus of claim 26, wherein the glass is fed to the bowl at an angle of 180 degrees such that the less desirable glass proceeds to the far end unusable edge section of the formed glass sheet.

28. The improved apparatus of claim 26, wherein the glass is fed to the bowl at an angle of approximately 45 degrees such that the less desirable glass proceeds to the inflow end unusable edge section of the formed glass sheet.

29. A method for reducing the sag rate of a forming trough having a longitudinal axis, a middle region, a first end, and a second end opposite the first end, said method comprising:

- a) supporting the forming trough at the first end and the second end;
- b) applying a moment at the first end; and

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- c) applying a moment at the second end such that the moment counteract stresses caused by a force of gravity, wherein the moment causes the thermal creep to occur primarily in the longitudinal direction, thus minimizing an effect on molten glass flow caused by sagging due to thermal creep in the middle region.

30. The method of claim 29, further comprising the steps of:

- d) applying a force at the first end; and
- e) applying a force at the second end.

31. An improved apparatus for forming sheet glass, wherein the apparatus includes a trough for receiving molten glass that has sides attached to a wedged shaped sheet forming structure that has downwardly sloping sides converging at the bottom of the wedge such that a glass sheet is formed when molten glass flows over the sides of the trough, down the downwardly sloping sides of the wedged shaped sheet forming structure and meets at the bottom of the wedge, and wherein the improvement comprises:

- a) at least one inlet end support block located at an inlet end of the trough, wherein the inlet end support block supports the trough; and
- b) at least one far end support block located at an opposite end of the trough as the inlet end support block, wherein the far end support block supports the trough; wherein the inlet end support block and the far end support block are shaped to distribute force in the trough to counteract the effect of the weight of the trough such that the force causes the thermal creep to occur primarily in the longitudinal direction.

* * * * *

UNITED STATES DISTRICT COURT
CENTRAL DISTRICT OF CALIFORNIA

BRUCE TECHNOLOGY LLC; RICHARD
PITBLADDO, AN INDIVIDUAL

PLAINTIFF(S)

v.

CORNING INCORPORATED, CORNING DISPLAY
TECHNOLOGIES TAIWAN CO., LTD., CORNING
JAPAN K.K., SHARP CORPORATION, SHARP
ELECTRONICS CORPORATION, SHARP ELECTRONICA
MEXICO S.A. DE C.V., LG.PHILIPS LCD CO., LTD.,
LG.PHILIPS LCD AMERICA, INC.,
AND DOE(S) 1 THROUGH 10,

DEFENDANT(S).

CASE NUMBER

CV08-00425 TJH (RCx)

SUMMONS

TO: DEFENDANT(S): _____

A lawsuit has been filed against you.

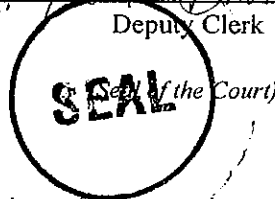
Within 20 days after service of this summons on you (not counting the day you received it), you must serve on the plaintiff an answer to the attached ☐ complaint ☒ FIRST amended complaint ☐ counterclaim ☐ cross-claim or a motion under Rule 12 of the Federal Rules of Civil Procedure. The answer or motion must be served on the plaintiff's attorney, Frederick A. Lorig, whose address is 865 S. Figueroa Street, 10th Floor, Los Angeles CA 90017. If you fail to do so, judgment by default will be entered against you for the relief demanded in the complaint. You also must file your answer or motion with the court.

Clerk, U.S. District Court

Dated: 17 APR 2008

By: *Arthur Davis*

Deputy Clerk



[Use 60 days if the defendant is the United States or a United States agency, or is an officer or employee of the United States. Allowed 60 days by Rule 12(a)(3)].