



(22) Date de dépôt/Filing Date: 1997/10/02

(41) Mise à la disp. pub./Open to Public Insp.: 1999/04/02

(45) Date de délivrance/Issue Date: 2001/08/07

(51) Cl.Int.⁶/Int.Cl.⁶ B03B 9/02

(72) Inventeurs/Inventors:

SIY, Robert, CA;
SPENCE, Jonathan, CA;
SURY, Ken, CA;
ALLCOCK, Geoff, CA

(73) Propriétaires/Owners:

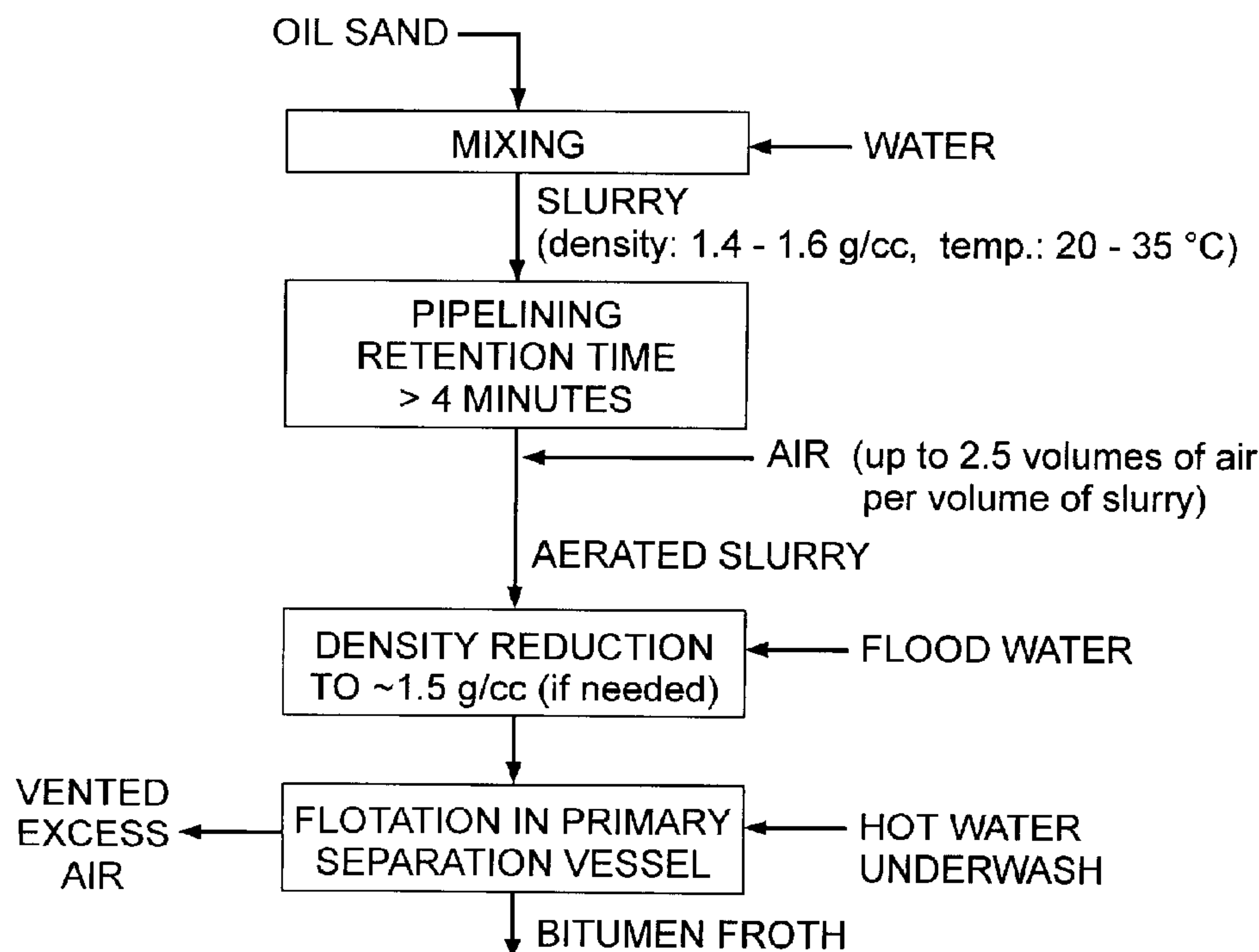
ALBERTA ENERGY COMPANY LTD., CA;
AEC Oil Sands Limited Partnership, CA;

...

(74) Agent: JOHNSON, ERNEST PETER

(54) Titre : PROCEDE D'EXTRACTION DU BITUME DES SABLES BITUMINEUX EN SUSPENSION EPAISSE FROIDE

(54) Title: COLD DENSE SLURRYING PROCESS FOR EXTRACTING BITUMEN FROM OIL SAND



(57) Abrégé/Abstract:

Average grade oil sand is mixed with water to produce a low temperature (preferably 20 - 35°C), dense (1.4 -1.65 g/cc) slurry. The slurry is pumped through a pipeline for sufficient time to condition it. Air is injected into the slurry after the last pump. The slurry density is adjusted to about 1.5 g/cc by adding flood water near the end of the pipeline. The slurry is introduced into a primary separation vessel (PSV), excess air is vented from the slurry as it is introduced into the PSV and a hot water underwash is used to heat the froth produced. Slurry loading to the PSV is greater than about 4.78 tonnes of oil sand/hour/square meter to reduce velocity gradient in the fluid in the vessel. Bitumen froth is recovered. When fed low grade oil sand, the process is modified by adding flotation aid chemicals to the slurry in the pipeline and subjecting the PSV tailings and middlings to secondary recovery with agitation and aeration in a secondary separation vessel.

(73) **Propriétaires(suite)/Owners(continued):** Athabasca Oil Sands Investments Inc., CA;
Canadian Occidental Petroleum Ltd., CA; Canadian Oil Sands Investments Inc., CA; Gulf Canada Resources Limited, CA;
Imperial Oil Resources, CA; Mocal Energy Limited, JP; Murphy Oil Company Ltd., CA; Petro-Canada Inc., CA

**"COLD DENSE SLURRYING PROCESS FOR
EXTRACTING BITUMEN FROM OIL SAND"**

ABSTRACT OF THE DISCLOSURE

Average grade oil sand is mixed with water to produce a low temperature (preferably 20 - 35°C), dense (1.4 – 1.65 g/cc) slurry. The slurry is pumped through a pipeline for sufficient time to condition it. Air is injected into the slurry after the last pump. The slurry density is adjusted to about 1.5 g/cc by adding flood water near the end of the pipeline. The slurry is introduced into a primary separation vessel (PSV), excess air is vented from the slurry as it is introduced into the PSV and a hot water underwash is used to heat the froth produced. Slurry loading to the PSV is greater than about 4.78 tonnes of oil sand/hour/square meter to reduce velocity gradient in the fluid in the vessel. Bitumen froth is recovered. When fed low grade oil sand, the process is modified by adding flotation aid chemicals to the slurry in the pipeline and subjecting the PSV tailings and middlings to secondary recovery with agitation and aeration in a secondary separation vessel.

FIELD OF THE INVENTION

1
2 This invention relates to a method for extracting bitumen from oil sand.
3 More particularly it relates to mixing oil sand with water to produce a dense,
4 low temperature slurry, pipelining the slurry a sufficient distance to condition
5 the slurry, aerating the slurry, feeding the aerated slurry to a primary
6 separation vessel maintaining a relatively low oil sand loading and venting
7 excess air from the slurry as it is fed to the vessel, to cause flotation of the
8 bitumen and gravity separation of the solids, to thereby recover bitumen in
9 froth form.

BACKGROUND OF THE INVENTION

10
11
12 Oil sand, as known in the Fort McMurray region of Alberta, comprises
13 water-wetted sand grains having viscous bitumen flecks trapped between the
14 grains. It lends itself to separating or dispersing the bitumen from the sand
15 grains by slurring the as-mined oil sand in water so that the bitumen flecks
16 move into the aqueous phase.

17 The bitumen in McMurray oil sand has been commercially recovered
18 for the past 25 years using the following general scheme (referred to as the
19 "hot water process"):

- 20 • dry mining the oil sand at a mine site that can be kilometers from an
21 extraction plant;
22 • conveying the as-mined oil sand on conveyor belts to the extraction
23 plant;

- 1 • feeding the oil sand into a rotating tumbler where it is mixed for a
2 prescribed retention time with hot water (80°C), steam, caustic and
3 naturally entrained air to yield a slurry typically having a
4 temperature of 80°C. The bitumen flecks are heated and become
5 less viscous. Chunks of oil sand are ablated or disintegrated. The
6 sand grains and bitumen flecks are dispersed or separate in the
7 water. To some extent bitumen flecks coalesce and grow in size.
8 They may contact air bubbles and coat them to become aerated
9 bitumen. The term used to describe this overall process in the
10 tumbler is "conditioning";
- 11 • the slurry produced is then diluted with additional hot water and
12 introduced into a large, open-topped, conical-bottomed, cylindrical
13 vessel (termed a primary separation vessel or "PSV"). The diluted
14 slurry is retained in the PSV under quiescent conditions for a
15 prescribed retention period. During this period, the aerated bitumen
16 rises and forms a froth layer which overflows the top lip of the
17 vessel and is conveyed away in a launder; and the sand grains sink
18 and are concentrated in the conical bottom - they leave the bottom
19 of the vessel as a wet tailings stream. Middlings, a watery mixture
20 containing solids and bitumen, extend between the froth and sand
21 layers. The tailings and middlings are withdrawn, combined and
22 sent to a secondary flotation process carried out in a deep cone
23 vessel wherein air is sparged into the vessel to assist with flotation.
24 This vessel is referred to as the TOR vessel. It and the process
25 conducted in it are disclosed in U.S. Patent 4,545,892.

1 The bitumen recovered is recycled to the PSV. The middlings from
2 the deep cone vessel are further processed in air flotation cells to
3 recover contained bitumen.

4 It is important to note that the process temperature in the tumbler and
5 PSV is in the order of 80°C. This high slurry temperature is used to reduce
6 the bitumen viscosity sufficiently so that it will readily separate from the sand
7 and coat the air bubbles in the aeration process. It also serves to enhance
8 the density difference between bitumen and water, which leads to more
9 effective flotation separation. The high temperature also promotes faster
10 disintegration of the oil sand lumps in the tumbler and faster coalescence of
11 the bitumen flecks in the PSV.

12 It is well understood in the industry that the quality of the oil sand has
13 very significant effects on the completeness of primary bitumen recovery in
14 the PSV and the quality of this froth (the froth from the PSV is termed
15 “primary” froth – that from the secondary circuit is termed “secondary” froth).
16 The quality of the useful oil sand produced from a mine will vary in grade.
17 The present invention is directed to establishing processes which are capable
18 of treating “low grade” and “average” oil sands to yield viable bitumen
19 recovery and froth quality at a lower energy input than the current commercial
20 processes. A “low grade” oil sand will contain between about 7 and 10 wt. %
21 bitumen. An average oil sand will contain at least 10 wt. % bitumen, typically
22 around 11 wt. %.

23 To be useful, a new or modified process for extracting bitumen from
24 low grade and average oil sands should achieve a total recovery value falling
25 within the extraction recovery curve set forth in Figure 1.

1 A fairly recent and major innovation in the oil sand industry has
2 involved:

- 3 • supplying heated water at the mine site;
- 4 • mixing the dry as-mined oil sand with the heated water at the mine
5 site in predetermined proportions using a device known as a
6 “cyclofeeder”, to form a slurry of controlled density having a
7 temperature in the range of 40 – 70°C, preferably about 50°C;
- 8 • screening the slurry to remove oversize solids too large to be fed to
9 the pipeline;
- 10 • pumping the screened slurry to the extraction plant through several
11 kilometers of pipeline; and
- 12 • feeding the slurry directly into the PSV.

13 This procedure relies on:

- 14 • the cyclofeeder successfully mixing the oil sand with the water in
15 pre-determined proportions at high rates while simultaneously
16 entraining some air within the slurry, thereby producing an aerated
17 slurry having a pre-determined density; and
- 18 • the pipeline providing ablation and retention time during which oil
19 sand lumps are disintegrated and bitumen flecks coalesce and coat
20 or attach to the air bubbles, so that the slurry is conditioned and
21 ready to go directly into the PSV and yield the required viable froth
22 yield and quality.

23 This innovation is disclosed in Canadian Patent No. 2,029,795 (Cymerman et
24 al) and United States Patent No. 5,039,227 (Leung et al), both assigned to the
25 present assignees.

1 The cyclofeeder operates on the principle of recycling part of the
2 produced slurry and introducing it tangentially into the vessel to produce a
3 vortex. The oil sand is delivered into the vortex. Water is added to the vortex,
4 to maintain the consistency of the slurry. An alternative to the cyclofeeder is
5 the trough system described in United States patent No. 5,772,127.

6 The innovation has enabled remote satellite mines to feed a central
7 extraction plant and has substantially eliminated conveyors and tumblers from
8 the process equipment.

9 Another innovation was developed by the OSLO group of companies.
10 This process involves:

- 11 • mixing oil sand with unheated water at the mine site using a
12 dredging procedure to produce a low density, ambient temperature
13 slurry;
- 14 • pumping this slurry through a pipeline to an extraction plant;
- 15 • adding air (1 to 1.5 volumes of air/volume of slurry) to the slurry in
16 the pipeline; and
- 17 • adding flotation aid chemicals (specifically a collector having the
18 characteristics of kerosene and a frother having the characteristics
19 of methyl-isobutyl-carbinol ("MIBC")) to the slurry while in the
20 pipeline to assist in later flotation in a PSV.

21 This process is disclosed in a paper "Dredging and cold water extraction
22 process for oil sands" by W. Jazrawi, delivered at a seminar convened in
23 March, 1990, by the Alberta Oil Sands and Technology Authority and United
24 States Patent No. 4,946,597 (K. N. Sury).

1 The OSLO process differs from the commercial hot water process and
2 the mixing/pipelining process in that it is carried out at ambient temperature.
3 Water at ambient temperature is used for slurry instead of expending energy
4 to heat water and then having to convey the hot water to the mine site in an
5 insulated pipeline.

6 The Jazrawi paper describes testing slurries having densities of
7 25 wt. % and 50 wt. % by weight solids in a pipeline test facility. However, the
8 stated slurrying process, dredging, offers little control over slurry density and
9 no control over temperature. Dredged oil sand slurry typically has a density in
10 the order of 1.2 to 1.3 g/cc. At this order of density, the process may lose
11 viability as a large volume of slurry has to be moved through the line and
12 processed to treat a specific quantity of oil sand. In addition the oil sand
13 loading of the PSV surface area will necessarily be low, leading to the need
14 for a very large PSV surface area.

15 The OSLO process also differs from the hot water process in that it is
16 thought that the bitumen flecks tend to attach to the air bubbles, rather than
17 coating them. The intimation is that, at low temperature, the bitumen is solid-
18 like rather than fluid in nature. The flotation aid chemicals are provided to
19 enhance the attachment mechanism. The Jazrawi paper indicates that the
20 dosage of flotation chemicals should increase as the grade of the oil sand
21 decreases.

22 With this background in mind, the present invention is now described.

1

SUMMARY OF THE INVENTION

2

In one embodiment, the invention provides a process for extracting

3

bitumen from an average oil sand, comprising:

4

- dry mining the oil sand;

5

- mixing the as-mined oil sand with water in predetermined

6

proportions near the mine site to produce a slurry containing

7

entrained air and having a controlled density in the range 1.4 to

8

1.65 g/cc and preferably a temperature in the range 20 - 35°C;

9

- pumping the slurry through a pipeline having a plurality of pumps

10

spaced along its length, the pipeline being connected to feed a

11

primary separation vessel ("PSV");

12

- preferably adding air to the slurry as it moves through the pipeline,

13

more preferably after the last pump, in an amount up to 2.5 volumes

14

of air per volume of slurry, to form an aerated slurry;

15

- introducing the slurry into the PSV, preferably so as to provide an

16

area loading greater than about 4.78 tonnes of oil sand/hour/square

17

meter, more preferably in the range of about 4.78 to 9.91 t/h/m²

18

and producing bitumen froth, tailings and middlings; and

19

- separately removing the froth, tailings and middlings from the PSV.

20

Inherent in the process defined by this embodiment, the following

21

concepts are brought together:

22

- the oil sand is dry mined and mixed at the mine site with water

23

using means such as a cyclofeeder to produce a dense slurry

24

having a low temperature;

- 1 • if the oil sand is of average or higher grade, we have discovered
2 that it can be pipelined in the form of a dense, low temperature
3 slurry, preferably with added aeration but without addition of
4 flotation aid chemicals, and then subjected to flotation in a PSV to
5 give viable primary bitumen recovery in the form of froth having
6 viable quality; and
- 7 • the dense, low temperature slurry can be fed at loading in the order
8 of about 4.78 – 9.91 t/h/m² into the PSV and still produce the
9 desired froth, thereby maintaining the high density nature of the
10 process.

11 Preferably, one or more of the following features are incorporated into
12 the basic process:

- 13 • operating the slurring and pipelining steps at a density in the order
14 of about 1.6 g/cc and a temperature in the order of 25°C;
- 15 • maintaining the slurry area loading to the PSV within generally
16 defined limits to ensure a vessel of adequate diameter so as to
17 facilitate bitumen flotation;
- 18 • pumping the slurry through a pipeline having sufficient length so
19 that the retention time is at least 4 minutes, to achieve conditioning;
- 20 • adjusting the density of the flotation step by adding flood water to
21 the slurry as it approaches the PSV to reduce its density to less
22 than 1.5 g/cc;
- 23 • venting excess air from the slurry as it is being introduced into the
24 PSV, through a vent stack associated with the incoming feed
25 distributor; and

- 1 • adding sufficient heated water as an underwash layer between the
2 froth and middlings in the PSV to ensure production of froth having
3 a temperature greater than about 35°C.

4 Inherent in the preferred process are the concepts of:

- 5 • operating the slurring and pipelining steps at low temperature and
6 high density; and then
7 • moderating density at the PSV, if required, to promote effective
8 flotation;
9 • maintaining slurry loading within limits to promote effective flotation;
10 • using an underwash of hot water to heat the froth and enable it to
11 flow more easily; and
12 • modifying the PSV step to cope with the large air content in the
13 slurry and minimize turbulence.

14 The best mode of the invention will be described below by way of
15 reporting on experimental tests.

16 The tests have demonstrated that:

- 17 • a well mixed, high density, low temperature slurry of average quality
18 oil sand,
19 • will condition adequately in a pipeline so as to yield viable primary
20 recovery of bitumen in the form of froth of viable quality, particularly
21 if the steps of air addition, excess air venting, slurry dilution and
22 slurry loading are incorporated, without the addition of flotation aid
23 chemicals, and

- 1 • the froth can be heated to at least 35°C by use of a hot water
2 underwash in the PSV, thereby assisting in removing the froth from
3 the PSV and satisfying downstream froth temperature needs.

4 In another aspect of the invention, we have shown that the process as
5 previously described can successfully be applied to low grade oil sand,
6 provided that:

- 7 • flotation aid chemicals are added to the slurry in the pipeline; and
8 • secondary recovery of bitumen by way of flotation with agitation and
9 submerged aeration is practiced.

10 We have further found that use of the OSLO flotation aid mixture of a collector
11 (such as kerosene) and a frother (such as MIBC), works satisfactorily with the
12 low temperature, dense slurry and air addition to create a slurry which, when
13 subjected to pipeline conditioning, primary quiescent flotation and secondary
14 agitated and sub-aerated flotation, yields enough bitumen recovery to satisfy
15 the curve of Figure 1.

16 Broadly stated, the invention is a method for recovering bitumen from
17 oil sand, comprising: dry mining oil sand from a deposit at a mine site; mixing
18 the oil sand near the mine site with water to produce a high density, low
19 temperature slurry containing bitumen, sand, water and entrained air, the
20 slurry having a density in the range of about 1.4 to 1.65 g/cc and a
21 temperature in the range of about 20 to 35°C; pumping the slurry through a
22 pipeline to a primary separation vessel; introducing the slurry from the pipeline
23 into the vessel and temporarily retaining it therein so that separate layers of
24 bitumen froth, middlings and sand tailings are formed; and separately
25 removing bitumen froth, middlings and sand tailings from the vessel.

DESCRIPTION OF THE DRAWINGS

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

Figure 1 is a curve in the form of a band, showing viable bitumen recoveries for various grades of oil sand;

Figure 2 is a block diagram setting forth the process in accordance with the invention, for use on average or higher grade oil sand feedstock;

Figure 3 is a schematic process flow diagram of a 100 tonne/hour field pilot circuit (hereinafter "100 tph circuit") used to demonstrate the average grade version of the process;

Figure 4 is a side elevation of the cyclofeeder used in the 100 tph circuit;

Figure 5 is a perspective view of the cyclofeeder of Figure 4;

Figure 6 is a top plan view of the cyclofeeder of Figure 4;

Figure 7 is a side elevation of the primary separator vessel ("PSV") used in the 100 tph circuit;

Figure 8 is a top plan view of the primary separator of Figure 7;

Figure 9 is a side elevation of a second smaller separator ("SSV") used in the 100 tph circuit to test secondary recovery slurry loading;

Figure 9a is a top plan view of the SSV of Figure 9;

Figure 10 is a schematic process flow diagram showing the PSV and SSV and the piping connected thereto;

Figure 11 is a schematic process flow diagram showing the pipeline assembly used in the 100 tph circuit;

Figure 12 is a block diagram setting forth the process in accordance with the invention, when practiced on low grade oil sand;

1 Figure 13 is a schematic process flow diagram of the 2 tonne/hour pilot
2 circuit (hereinafter "2 tph circuit") used to demonstrate the low grade version
3 of the process;

4 Figure 14a is a side elevation of the cyclofeeder used in the 2 tph
5 circuit;

6 Figure 14b is a top plan view of the cyclofeeder of Figure 14a;

7 Figure 14c is an end side view of the cyclofeeder of Figure 14a;

8 Figure 15 is a side elevation of the PSV used in the 2 tph circuit;

9 Figure 16 is a partial side elevation of the secondary recovery vessel,
10 referred to as the TOR (tailings oil recovery), used in the 2 tph circuit.

11

12 **DESCRIPTION OF THE PREFERRED EMBODIMENT**

13 **Example I – Pilot Demonstration**

14 This example describes a run in a 100 tonne per hour of oil sand field
15 pilot circuit at optimum conditions, demonstrating the viability of the best mode
16 of the process when applied to average grade oil sand.

Summary

The feedstock was average grade oil sand containing 11.1 wt. % bitumen and 6% fine solids < 44 μ m. The process involved mixing of the oil sand and water in a cyclofeeder to produce a slurry having a density of about 1.55 g/cc. The temperature of the slurry was 26 - 27°C. The slurry was conditioned by pumping it through a 102 mm diameter pipeline having a length of 1.1 kilometers and retention time of about 4 minutes. Air was added to the slurry in the pipeline just before the PSV to provide an air to slurry volume ratio of about 1.5. The slurry was diluted with flood water prior to entering the PSV to modify the density to 1.4 g/cc. Hot water (80°C) was injected as an underwash and raised the froth temperature to 33°C, adequate for subsequent processing. The oil sand loading of the PSV was about 4.78 tonne/hr./m².

Results

The average recovery achieved was about 98% bitumen on a reject free basis, with a bitumen primary froth quality of about 59% bitumen, 21% water and 20% solids based on weight.

Equipment and Conditions

The 100 tph circuit is shown in Figure 3. It comprised:

- A pile 1 of as-mined oil sand;
- An oil sand feed system 2 comprising a front end loader 3, vibrating grizzly 4 for screening out or rejecting +12 inch lumps, a conveyor 5 for transporting the -12 inch oil sand, a second vibrating grizzly 6 for receiving the -12 inch oil sand and rejecting the +4 inch material

1 and a feed conveyor 7 for transporting the screened undersize to
2 the cyclofeeder;

- 3 • A cyclofeeder system 10 comprising a cyclofeeder 11, a source 12
4 of process water for supplying the cyclofeeder, a vibrating screen
5 13 for rejecting +1 inch oversize from the underflow from the
6 cyclofeeder and a pump box 14 for collecting the cyclofeeder
7 underflow. This cyclofeeder system 10 is described in United
8 States Patent No. 5,039,227. The cyclofeeder is shown in Figures
9 4, 5 and 6. The cyclofeeder system 10 is operative to mix oil sand
10 and water, in pre-determined proportions, to create an oil sand
11 slurry having a controlled or pre-determined density. Some air is
12 entrained in the slurry during mixing. The cyclofeeder 11 was 1200
13 mm in diameter, 1200 mm in height, and had a bottom cone
14 opening of 330 mm. It discharged slurry onto a vibrating screen 13
15 having a single deck (0.9 m by 3.0 m) of woven wire mesh having
16 an opening size of 25 mm. Hot water at 80°C was sprayed onto the
17 screen to prevent blinding. Slurry was pumped and recycled from
18 the pump box 14 to the cyclofeeder 11 through line 15 to maintain a
19 steady vortex in the cyclofeeder. The weight ratio of recycle flow to
20 pipeline flow was approximately 3:1;
- 21 • A slurry pipeline 20, shown in Figures 3 and 11. It was designed to
22 operate at an oil sand feed rate from 75 to 100 t/h. It consisted of a
23 series of six sections, with a total length of up to 3 km. Two pumps
24 21 powered each section. The slurry velocity within the pipeline
25 was between 2.5 and 3.5 m/s;

- 1 • An air and dilution water addition system. Air from a compressor 31
2 was injected into the slurry about 360 meters before the end of the
3 pipeline through a 37 mm diameter nozzle having 5 mm diameter
4 orifices. The diameter of the pipeline at the air injection point was
5 increased to 150 mm to accommodate the increased stream
6 volume. Flood water was also added, if required, from a source 30
7 to the slurry just downstream of the air addition point, to modify the
8 slurry density. The diluted and aerated slurry was retained in the
9 pipeline for about 2 minutes following addition;
- 10 • A primary separation vessel 40 ("PSV"). This vessel is shown in
11 Figures 7 and 8. Associated with it were an underflow pump 41 and
12 a froth weighing system 42. The PSV had a diameter of 5.18 m in
13 the cylindrical section. The vessel was of the deep cone type
14 (angle of cone 60°). The vessel had a central feed slurry distributor
15 43. This was a 0.92 m diameter pipe having openings in its side
16 wall. A vent stack 44 extended up from the distributor, for venting
17 excess air from the entering slurry, to reduce turbulence. A froth
18 underwash pipe 45 extended down into the vessel chamber 46 and
19 extended horizontally around the vent stack just below the expected
20 level of the froth/middlings interface. The froth underwash ("U/W")
21 pipe had four outlets 47 for injecting heated underwash water into
22 the vessel chamber. The froth U/W pipe vertically entered the PSV
23 1295 mm from the vessel center. The feedwell radius was 460 mm
24 and the vessel radius was 2590 mm. The water exited the outlets
25 47 870 mm below the froth overflow lip elevation. The

1 froth/middlings interface generally stayed 250 to 500 mm above the
2 U/W outlets 47. The tailings left the vessel through a bottom outlet
3 48. Middlings could be withdrawn through pipe 49 – however this
4 was not done during the tests described herein. The froth
5 overflowed into a launder 50 and was conveyed into the box of a
6 truck 51 standing on a weigh scale for measuring froth production
7 rate;

- 8 • A secondary separation vessel 60 ("SSV"). This vessel is shown in
9 Figures 9 and 9a. The SSV has been shown because it was used
10 in a vessel loading experiment described hereunder. It was also
11 operated in these runs, but was found to be unnecessary because
12 its recovery was negligible. It was also a deep cone vessel having
13 similar internals to the PSV. It was smaller, being 3.66 m in
14 diameter and having a cone angle of 60°. It was equipped with a
15 tailings outlet 61, middlings removal pipe 62, launder 63, underflow
16 pump 64, froth weighing means 65, slurry distributor 66, vent stack
17 67, and underwash pipe 68, substantially in accordance with the
18 PSV. The underflow slurry from the PSV was mixed with air in line
19 69 using an in-line aeration nozzle similar to that of the pipeline 20.
20 The PSV underflow slurry was conditioned through 180 meters of
21 150 mm diameter line 69 and then introduced into the SSV for
22 additional bitumen recovery. The underflow from the SSV was
23 discarded in a pit. The froth produced was deposited into the box of
24 a truck 70 standing on a weigh scale;

- The pilot plant was equipped with instrumentation to measure flow rate, temperature and density of all process streams. The signals from the instruments were fed to an Allen Bradley 5/40 E Programmable Logic Controller ("PLC"), which was used for all process control functions except oil sand and chemical rate control. A Man Machine Interface ("MMI"), comprising a PC based system using Intellution Fix DMACS, was provided for data logging and trending. A Ramsey mechanical belt weigh scale was used to measure oil sand feed rate to the cyclofeeder. Samples were taken of the following streams for material balances: oil sand; cyclofeeder screen rejects; pipeline exit slurry; PSV froth; PSV underflow; SSV froth; and SSV underflow. Samples were analyzed for density, OWS, PSD, froth aeration and froth viscosity.

Conditions and Results

The conditions and averaged results of a series of 6 runs are now set forth in Tables I and II, now set forth.

1 TABLE I

2 DEMONSTRATION RUN CONDITIONS – AVERAGE GRADE OIL SAND

3

Oil Sand Feed	t/h	101
Pipeline Length	Km	1.1
Pipeline: No. of Pumps		6
4" Pipeline Inlet temperature	°C	26
4" Pipeline Outlet temperature	°C	27
4" Pipeline Velocity	m/s	3.0
4" Pipeline Feed Density	kg/m ³	1548
Pipeline Air to Slurry Ratio	vol/vol	1.5
MIBC	ppm oil sand	0
Hydrocarbon additive	ppm oil sand	0
Vessel Selection (PSV,SSV)		PSV
Separation Circuit		PSV only
PSV Feed Density, excluding Air	kg/m ³	1402
PSV Slurry Feed Temperature	°C	24
PSV Underwash/Oil Sand Ratio	%	8
PSV Underflow Density, exc. Air	kg/m ³	1410
SSV Air to Slurry Ratio	vol/vol	1
SSV Slurry Feed Temperature	°C	29
SSV Underwash/Oil Sand	%	6

TABLE II

Demonstration Results – Average Grade Oil Sand

Rejects (Based on Oil Sand Rate)	%	2.5
Rejects Bitumen Loss (Based on Oil Sand Feed)	%	1.4
PSV Bitumen Recovery (Based on PSV Feed)	%	98.1
PSV Froth Bitumen	%	59.1
PSV Froth Solids	%	20.2
PSV Underflow Bitumen Loss (Based on PSV Feed)	%	1.9
PSV Underflow Bitumen	%	0.1
PSV Underflow Solids	%	46.7

The foregoing data provide the conditions used and results obtained in a group of runs which were averaged, the runs having been carried out on average oil sand at selected conditions in the pilot plant. A number of other runs were carried out with varied conditions and are supported by a substantial body of experimentation at laboratory bench and 2 tonne/hour pilot scales. From this overall program, we have established:

- 1 • That the density of the mixed slurry introduced into the pipeline
2 should be in the range 1.4 to 1.65 g/cc. If the density is less than
3 about 1.4 g/cc, the system has reduced oil sand capacity. If the
4 density is greater than about 1.65 g/cc, the pipeline operation is
5 characterized by high head loss and a potential for sanding out and
6 plugging;
- 7 • That the temperature of the mixed slurry issuing from the pipeline
8 should be in the range 20 - 35°C. If the temperature is less than
9 about 20°, bitumen recovery will be lower. If the temperature is
10 greater than about 35°C, the system is wasting energy;
- 11 • That the aeration ratio should be up to about 2.5, preferably 1 – 2.5,
12 volumes of air per volume of slurry. If the ratio is less than 1,
13 bitumen recovery may be reduced. There is no improvement if the
14 ratio is increased above 2.5.

15 **Example II – Effects of Chemical Addition**

16 This example demonstrates that the process of the invention can be
17 practised on average oil sand without the use of flotation aids to yield viable
18 bitumen recovery as primary froth of viable quality.

19 The pilot circuit described in Example I was used.

20 Runs with and without flotation aid chemicals were carried out for
21 comparison. The relevant conditions and results are set forth in Table III now
22 following:

TABLE III

EFFECTS OF CHEMICAL ADDITION – AVERAGE GRADE OIL SAND

MIBC, ppm oil sand	0	33
Hydrocarbon additive, ppm oil sand	0	27
4" Pipeline Inlet Temperature, °C	26	25
4" Pipeline Outlet Temperature, °C	27	27
4" Pipeline Feed Density, kg/m ³	1548	1526
Pipeline Air to Slurry Ratio, vol/vol	1.5	1.5
PSV Feed Density, excluding Air, kg/m ³	1402	1402
Rejects (Based on Oil Sand Rate), %	2.5	11.8
Rejects Bitumen Loss (Based on Oil Sand Feed), %	1.43	7.10
PSV Bitumen Recovery (Based on PSV Feed), %	98.1	97.8
PSV Froth Bitumen, %	59.1	62.0
PSV Froth Solids, %	20.2	18.9
PSV Underflow Bitumen Loss (Based on PSV Feed), %	1.9	2.2
PSV Underflow Bitumen, %	0.1	0.1
PSV Underflow Solids, %	46.7	45.5

Example III - Loading

This example demonstrates that the process is amenable to high loading of the PSV with slurry having high density. Two runs were carried out in the pilot circuit of Example I, using the large PSV 40 in one run and the smaller SSV 60 in the other run as the primary separation vessel. As the vessels had different surface areas, the runs involved "low" and "high" oil sand loading.

1 The relevant conditions and results are set forth in Table IV and V now
2 following:

3 TABLE IV

4 PSV LOADING COMPARISON

Parameter		Pilot Vessel 40 as PSV	Pilot Vessel 60 as PSV
PSV DIAMETER	M	5.18	3.66
Oil Sand Rate (After Rejects)	t/h	97.6	97.6
Oil Sand Loading	t/h/ft2	0.44	0.91
	t/h/m2	4.78	9.91
Solids Loading	t/h/m2	4.06	8.42
Bitumen Loading	t/h/m2	0.53	1.09

1

TABLE V

2

LOADING STUDY RESULTS – AVERAGE GRADE OIL SAND

PSV		Vessel 40	Vessel 60
Rejects (Based on Oil Sand Rate)	%	2.5	3.0
Rejects Bitumen Loss (Based on Oil Sand Feed)	%	1.4	1.8
PSV Bitumen Recovery (Based on PSV Feed)	%	98.1	96.6
PSV Froth Bitumen	%	59.1	61.8
PSV Froth Solids	%	20.2	19.9
PSV Froth Solids/Bitumen ratio	%	0.34	0.32
PSV Underflow Bitumen Loss (Based on PSV Feed)	%	1.9	3.4
PSV Underflow Bitumen	%	0.1	0.2
PSV Underflow Solids	%	46.7	45.3

1 **Example IV – Low Grade Oil Sand**

2 This example demonstrates that low grade oil sands can successfully
3 be processed using the mixing/pipelining/flotation procedure with low
4 temperature dense slurry, provided that:

- 5 • Flotation aid chemicals (hereinafter “flotation aids”) are used; and
- 6 • The underflow tailings from the PSV are subjected to secondary
7 recovery using submerged aeration and agitation.

8 **Feedstock**

9 The low grade oil sand feedstock contained 8.2% bitumen and had an
10 average fines content of 33% (less than 44µm).

11 **Circuit**

12 The feedstock was processed in a 1-2 tonnes/hour pilot circuit (see
13 Figure 13). This circuit comprised a vibrating grizzly (not shown) with 3” x 4”
14 openings, for removing oversize material from oil sand feed. The product was
15 delivered into a cyclofeeder 101 by a conveyor 102. Water was introduced
16 from a source 103 into the cyclofeeder through line 104. The cyclofeeder
17 comprised a vessel 105 20 inches in diameter. The bottom cone 106 had an
18 angle of 30 degrees with the horizontal. The cyclofeeder discharged onto a
19 double deck vibrating screen 107. The top deck of the screen had 2 inch
20 square openings and the lower deck had 3/8 inch square openings. The
21 screened slurry dropped into a pump box 108. Part of the slurry in the pump
22 box was pumped and recycled via the line 109 back into the cyclofeeder, to
23 maintain the vortex therein. The remainder of the slurry in the pump box was
24 pumped through line 111 to a pipeline loop 112. Flotation aids could be
25 injected from sources 114, 114a into line 111. The pipeline loop was 2 inches

1 in diameter and had a length of 47 meters. It comprised a chiller 116 for
2 cooling the slurry if required. The slurry delivered through line 111 was
3 pumped through the loop 112 by pump 200. The slurry leaving the loop was
4 transferred through line 115 to the PSV 117. Flood water could be injected
5 from a source 118 into line 115. Air at 75 psi could also be injected as
6 bubbles into line 115 from a source 119. Aerated slurry residence time in the
7 line 115 was about 20 seconds. The aerated slurry was introduced into the
8 PSV 117 using a feedwell equipped with a chimney. The PSV 117 is shown
9 in Figure 15 and comprised a deep cone vessel 121 having a cylindrical upper
10 section and conical lower section. The vessel 121 diameter was 800 mm.
11 Hot water from a source 122 could be introduced through an underwash pipe
12 123 centrally located just beneath the expected froth/middlings interface. A
13 central vent stack 124 was provided to allow excess air to escape and reduce
14 turbulence in the vessel. Froth overflowed into a launder 125. The froth
15 flowed down a trough 126 into primary froth weigh tanks (not shown). The
16 PSV was operated as a two phase separator, producing a froth and a tailings
17 underflow. The PSV underflow was fed through line 128 to a TOR vessel
18 129, for additional bitumen recovery. The TOR vessel is shown in Figure 16.
19 It was equipped with an agitator 130 supplied with air through a line 131, for
20 producing air bubbles. It was also operated as a two phase separator,
21 producing a froth and a tailings underflow. The TOR underflow was pumped
22 to a tailings weigh tank (not shown) as the final tailings stream.

- 1 A series of runs were carried out wherein:
- 2 • MIBC/kerosene dosage;
 - 3 • Air/slurry volume ratio; and
 - 4 • Underwash water/oil sand feed ratio,
- 5 were varied, to determine their effect on bitumen recovery.

6 Conditions and Results

- 7 The low grade oil sand process target conditions were:
- 8 • Pipeline slurry density – 1.60 g/cc
 - 9 • Pipeline slurry temperature - 25°C
 - 10 • Pipeline residence time – 8 minutes
 - 11 • Pipeline slurry velocity – 3/ms
 - 12 • Oil sand target feed rate – 1.5 tph
 - 13 • Froth underwash water target temperature - 70°C
 - 14 • TOR air addition rate – 120 SCFH at 48 psi.
- 15 The remaining experimental conditions are set forth in Table VI, together with
- 16 the run results.

1 **TABLE VI**

Run	Operating Conditions				PSV Froth			TOR Froth			Combined Froth		
	PSV Final Feed Density, g/cc	Chem. Conc.	Air Ratio	Underwash Ratio	Recovery %	Bitumen Wt%	Solids Wt%	Recovery %	Bitumen Wt%	Solids Wt%	Recovery %	Bitumen Wt%	Solids Wt%
1	1.39	357	1.5	0.168	39.87	58.84	12.30	48.13	38.80	22.01	88.00	45.88	18.58
2	1.40	357	1.5	0.168	51.33	62.64	13.78	39.44	41.15	22.20	90.76	51.05	18.32
3	1.40	357	1.0	0.168	44.46	64.06	14.64	45.40	45.53	23.70	89.87	52.83	20.13
4	1.40	265	1.5	0.168	54.79	61.40	13.65	35.00	42.74	22.67	89.80	52.47	17.97
5	1.39	265	1.5	0.168	40.10	60.38	14.04	48.13	41.91	23.30	88.23	48.68	19.91
6	1.39	316	0.6	0.127	26.42	54.38	11.97	54.56	38.44	23.29	80.98	42.51	20.40
7	1.40	232	0.6	0.127	34.35	56.36	12.50	49.52	44.04	20.30	83.88	48.37	17.56
8	1.39	232	2.0	0.127	49.20	50.47	11.65	35.84	42.51	21.96	85.04	46.78	16.43
9	1.38	308	1.0	0.127	35.64	53.12	12.19	40.68	32.75	22.31	76.32	39.89	18.76
10	1.38	308	2.0	0.127	29.61	45.92	13.48	42.08	31.16	22.59	71.70	35.93	19.65
11	1.39	0	2.0	0.127	20.02	44.27	12.35	44.35	33.71	20.89	64.39	36.41	18.70
12	1.38	347	1.5	0.127	33.93	45.12	10.39	38.21	31.79	21.86	72.14	36.92	17.45
13	1.39	400	1.5	0.127	32.56	45.90	10.09	42.95	32.56	21.39	75.50	37.22	17.44
14	1.40	400	1.5	0.127	31.84	45.51	10.30	43.60	32.64	21.71	75.45	37.06	17.79
15	1.40	424	1.5	0.127	29.09	47.79	11.18	46.32	33.51	21.00	75.41	37.88	18.00
16	1.40	424	1.5	0.127	28.40	46.67	11.08	45.49	32.42	22.35	73.89	36.73	18.94

1 The following observations can be made with respect to the
2 experimental results:

- 3 • The process was effective in achieving bitumen recovery as high as
4 90.76% (see run 2);
- 5 • The use of chemical flotation aids (MIBC and kerosene) was found
6 to be necessary for the low grade oil sand (see runs 11 and 2);
- 7 • PSV, TOR and combined froth bitumen content were inversely
8 related to air/slurry volume ratio (see runs 6, 9 and 10);
- 9 • Increasing PSV froth underwash rate improved bitumen recovery
10 (see runs 2 and 12).

11 **Example V**

12 This example demonstrates that use of mechanical agitation in the
13 secondary recovery TOR vessel gives better recovery than is experienced
14 without agitation.

15 Table VII compares the average bitumen recoveries obtained with the
16 100 tph circuit of Example I with the 2 tph circuit of Example IV, using low
17 grade oil sand as the feed. For the 100 tph circuit, the secondary separation
18 vessel was a gravity settling vessel, whereas for the 2 tph circuit, the
19 secondary separation vessel was a TOR vessel with a mechanical agitator.
20 The results are set forth in Table VII.

TABLE VII**RECOVERY COMPARISON FOR 100 tph
AND 2 tph CIRCUITS**

	Average Recovery, %		
Circuit	PSV	SSV or TOR	Combined
100 tph circuit	52.7	7.6	60.3
2 tph circuit	35.2	44.5	79.7

It will be noted that a significantly higher combined bitumen recovery was obtained from the 2 tph circuit than from the 100 tph circuit, because a significant amount of this recovery was achieved from the secondary recovery in the 2 tph circuit. The average secondary and combined bitumen recoveries were 8 – 12% and 60 – 68%, respectively, for the 100 tph circuit and 35 – 45% and 75 – 80%, respectively, for the 2 tph circuit.

1 **THE EMBODIMENTS OF THE INVENTION IN WHICH AN**
2 **EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS**
3 **FOLLOWS:**

4
5 1. A method for recovering bitumen from oil sand, comprising:
6 dry mining oil sand from a deposit at a mine site;
7 mixing the oil sand near the mine site with water to produce a high
8 density, low temperature slurry containing bitumen, sand, water and entrained
9 air, the slurry having a density in the range of about 1.4 to 1.65 g/cc and a
10 temperature in the range of about 20 to 35 °C;
11 pumping the slurry through a pipeline to a primary separation vessel;
12 introducing the slurry from the pipeline into the vessel and temporarily
13 retaining it therein so that separate layers of bitumen froth, middlings and
14 sand tailings are formed; and
15 separately removing bitumen froth, middlings and sand tailings from
16 the vessel.

17
18 2. The method as set forth in claim 1 comprising:
19 adding air to the slurry as it moves through the pipeline to form an
20 aerated slurry.

21
22 3. The method as set forth in claim 2 comprising:
23 venting excess air from the slurry as it is being introduced into the
24 vessel.

1 4. The method as set forth in claim 3 comprising:
2 diluting the slurry with water prior to introducing it into the vessel, if
3 required, to ensure that its density is less than about 1.5 g/cc.

4

5 5. The method as set forth in claim 4 comprising:
6 maintaining the area loading of slurry to the vessel greater than about
7 4.78 t/h/m².

8

9 6. The method as set forth in claim 5 wherein:
10 the pipeline has sufficient length so that the retention time therein is at
11 least 4 minutes.

12

13 7. The method as set forth in claim 6 wherein the area loading of slurry
14 to the vessel is maintained within the range of about 4.78 to 9.91 t/h/m².

15

16 8. The method as set forth in claim 5 comprising:
17 heating bitumen in the vessel by adding heated water as an underwash
18 layer immediately beneath the bitumen froth layer.

19

20 9. The method as set forth in claim 8 wherein:
21 the amount of air added to the slurry in the pipeline is about 1 to 2.5
22 volumes of air per volume of slurry.

23

24 10. The method as set forth in claims 1, 2, 3, 4, 5, 6, 7, 8 or 9 wherein
25 the oil sand is of at least about average grade.

1 11. The method as set forth in claims 1, 2, 3, 4, 5, 6, 7, 8 or 9 wherein
2 the oil sand is of at least about average grade, the slurry is moved through the
3 pipeline by a plurality of pumps spaced along its length and the added air is
4 introduced into the slurry after the last pump and prior to the vessel.

5

6 12. The method as set forth in claim 3 comprising:
7 maintaining the area loading of slurry to the vessel greater than about
8 4.78 t/h/m².

9

10 13. The method as set forth in claim 12 wherein:
11 the pipeline has sufficient length so that the retention time therein is at
12 least 4 minutes.

13

14 14. The method as set forth in claim 13 wherein the area loading of
15 slurry to the vessel is maintained within the range of about 4.78 to 9.91 t/h/m².

16

17 15. The method as set forth in claim 14 comprising:
18 heating bitumen in the vessel by adding heated water as an underwash
19 layer immediately beneath the bitumen froth layer.

20

21 16. The method as set forth in claims 12, 13, 14 or 15 wherein:
22 the amount of air added to the slurry in the pipeline is about 1 to 2.5
23 volumes of air per volume of slurry.

1 17. The method as set forth in claims 12, 13, 14 or 15 wherein the oil
2 sand is of at least about average grade.

3

4 18. The method for recovering bitumen from low grade oil sand,
5 comprising:

6 dry mining oil sand from a deposit at a mine site;

7 mixing the oil sand near the mine site with water to produce a high
8 density, low temperature slurry containing bitumen, sand, water and entrained
9 air, the slurry having a density in the range of about 1.4 to 1.65 g/cc and a
10 temperature in the range of about 20 to 35 °C;

11 pumping the slurry through a pipeline to a primary separation vessel;

12 adding air and a flotation aid to the slurry, the air being added to the
13 slurry as it moves through the pipeline, to form an aerated slurry;

14 introducing the aerated slurry from the pipeline into the vessel and
15 temporarily retaining it therein so that separate layers of bitumen froth,
16 middlings and sand tailings are formed; and

17 separately removing bitumen froth, middlings and sand tailings from
18 the vessel.

19

20 19. The method as set forth in claim 18 comprising:

21 venting excess air from the slurry as it is being introduced into the
22 vessel.

1 20. The method as set forth in claim 19 comprising:
2 diluting the slurry with water prior to introducing it into the vessel, if
3 required, to ensure that its density is less than about 1.5 g/cc.

4

5 21. The method as set forth in claim 20 comprising:
6 maintaining the area loading of slurry to the vessel greater than about
7 4.78 t/h/m².

8

9 22. The method as sets forth in claim 21 wherein:
10 the pipeline has sufficient length so that the retention time therein is at
11 least 4 minutes.

12

13 23. The method as set forth in claim 22 wherein the area loading of
14 slurry to the vessel is maintained within the range of about 4.78 to 9.91 t/h/m².

15

16 24. The method as set forth in claim 21 comprising:
17 heating bitumen in the vessel by adding heated water as an underwash
18 layer immediately beneath the bitumen froth layer.

1 25. A method for recovering bitumen from oil sand, comprising:
2 dry mining oil sand from a deposit at a mine site;
3 mixing the oil sand near the mine site with water to produce a high
4 density, low temperature slurry containing bitumen, sand, water and entrained
5 air, the slurry having a density in the range of about 1.4 to 1.65 g/cc and a
6 temperature in the range of 20 to 40°C;
7 pumping the slurry through a pipeline to a primary separation vessel;
8 introducing the slurry from the pipeline into the vessel and temporarily
9 retaining it therein so that separate layers of bitumen froth, middlings and
10 sand tailings are formed; and
11 separately removing bitumen froth, middlings and sand tailings from
12 the vessel.

13
14 26. The method as set forth in claim 25 comprising:
15 adding air to the slurry as it moves through the pipeline to form an
16 aerated slurry.

17
18 27. The method as set forth in claim 26 comprising:
19 venting excess air from the slurry as it is being introduced into the
20 vessel.

21
22 28. The method as set forth in claim 27 comprising:
23 diluting the slurry with water prior to introducing it into the vessel, if
24 required, to ensure that its density is less than about 1.5 g/cc.

25

1 29. The method as set forth in claim 28 comprising:
2 maintaining the area loading of slurry to the vessel greater than about
3 4.78 t/h/m².

4

5 30. The method as set forth in claim 29 wherein:
6 the pipeline has sufficient length so that the retention time therein is at
7 least 4 minutes.

8

9 31. The method as set forth in claim 30 wherein the area loading of
10 slurry to the vessel is maintained within the range of about 4.78 to 9.91 t/h/m².

11

12 32. The method as set forth in claim 29 comprising:
13 heating bitumen in the vessel by adding heated water as an underwash
14 layer immediately beneath the bitumen froth layer.

15

16 33. The method as set forth in claim 32 wherein:
17 the amount of air added to the slurry in the pipeline is about 1 to 2.5
18 volumes of air per volume of slurry.

19

20 34. The method as set forth in claims 25, 26, 27, 28, 29, 30, 31, 32 or
21 33 wherein the oil sand is of at least about average grade.

1 35. The method as set forth in claims 25, 26, 27, 28, 29, 30, 31, 32 or
2 33 wherein the oil sand is of at least about average grade, the slurry is moved
3 through the pipeline by a plurality of pumps spaced along its length and the
4 added air is introduced into the slurry after the last pump and prior to the
5 vessel.

6

7 36. The method as set forth in claim 27 comprising:
8 maintaining the area loading of slurry to the vessel greater than about
9 4.78 t/h/m².

10

11 37. The method as set forth in claim 36 wherein:
12 the pipeline has sufficient length so that the retention time therein is at
13 least 4 minutes.

14

15 38. The method as set forth in claim 37 wherein the area loading of
16 slurry to the vessel is maintained within the range of about 4.78 to 9.91 t/h/m².

17

18 39. The method as set forth in claim 38 comprising:
19 heating bitumen in the vessel by adding heated water as an underwash
20 layer immediately beneath the bitumen froth layer.

21

22 40. The method as set forth in claims 36, 37, 38 or 39 wherein:
23 the amount of air added to the slurry in the pipeline is about 1 to 2.5
24 volumes of air per volume of slurry.

1 41. The method as set forth in claims 36, 37, 38 or 39 wherein the oil
2 sand is of at least about average grade.

3

4 42. The method for recovering bitumen from low grade oil sand,
5 comprising:

6 dry mining oil sand from a deposit at a mine site;

7 mixing the oil sand near the mine site with water to produce a high
8 density, low temperature slurry containing bitumen, sand, water and entrained
9 air, the slurry having a density in the range of about 1.4 to 1.65 g/cc and a
10 temperature in the range of 20 to 40°C;

11 pumping the slurry through a pipeline to a primary separation vessel;

12 adding air and a flotation aid to the slurry, the air being added to the
13 slurry as it moves through the pipeline, to form an aerated slurry;

14 introducing the aerated slurry from the pipeline into the vessel and
15 temporarily retaining it therein so that separate layers of bitumen froth,
16 middlings and sand tailings are formed; and

17 separately removing bitumen froth, middlings and sand tailings from
18 the vessel.

19

20 43. The method as set forth in claim 42 comprising:

21 venting excess air from the slurry as it is being introduced into the
22 vessel.

1 44. The method as set forth in claim 43 comprising:
2 diluting the slurry with water prior to introducing it into the vessel, if
3 required, to ensure that its density is less than about 1.5 g/cc.

4

5 45. The method as set forth in claim 44 comprising:
6 maintaining the area loading of slurry to the vessel greater than about
7 4.78 t/h/m².

8

9 46. The method as sets forth in claim 45 wherein:
10 the pipeline has sufficient length so that the retention time therein is at
11 least 4 minutes.

12

13 47. The method as set forth in claim 46 wherein the area loading of
14 slurry to the vessel is maintained within the range of about 4.78 to 9.91 t/h/m².

15

16 48. The method as set forth in claim 45 comprising:
17 heating bitumen in the vessel by adding heated water as an underwash
18 layer immediately beneath the bitumen froth layer.

1/12

FIG. 1.

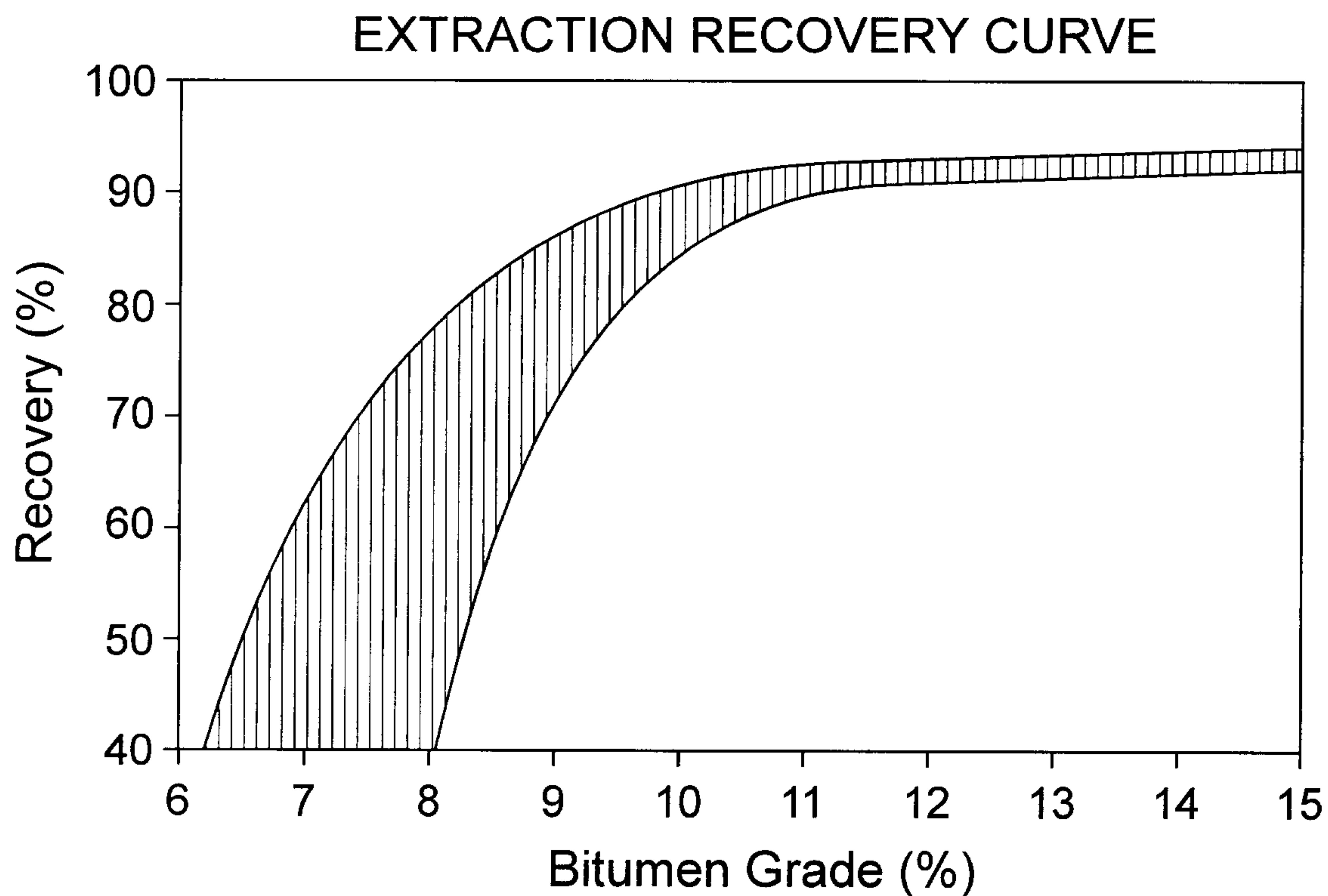
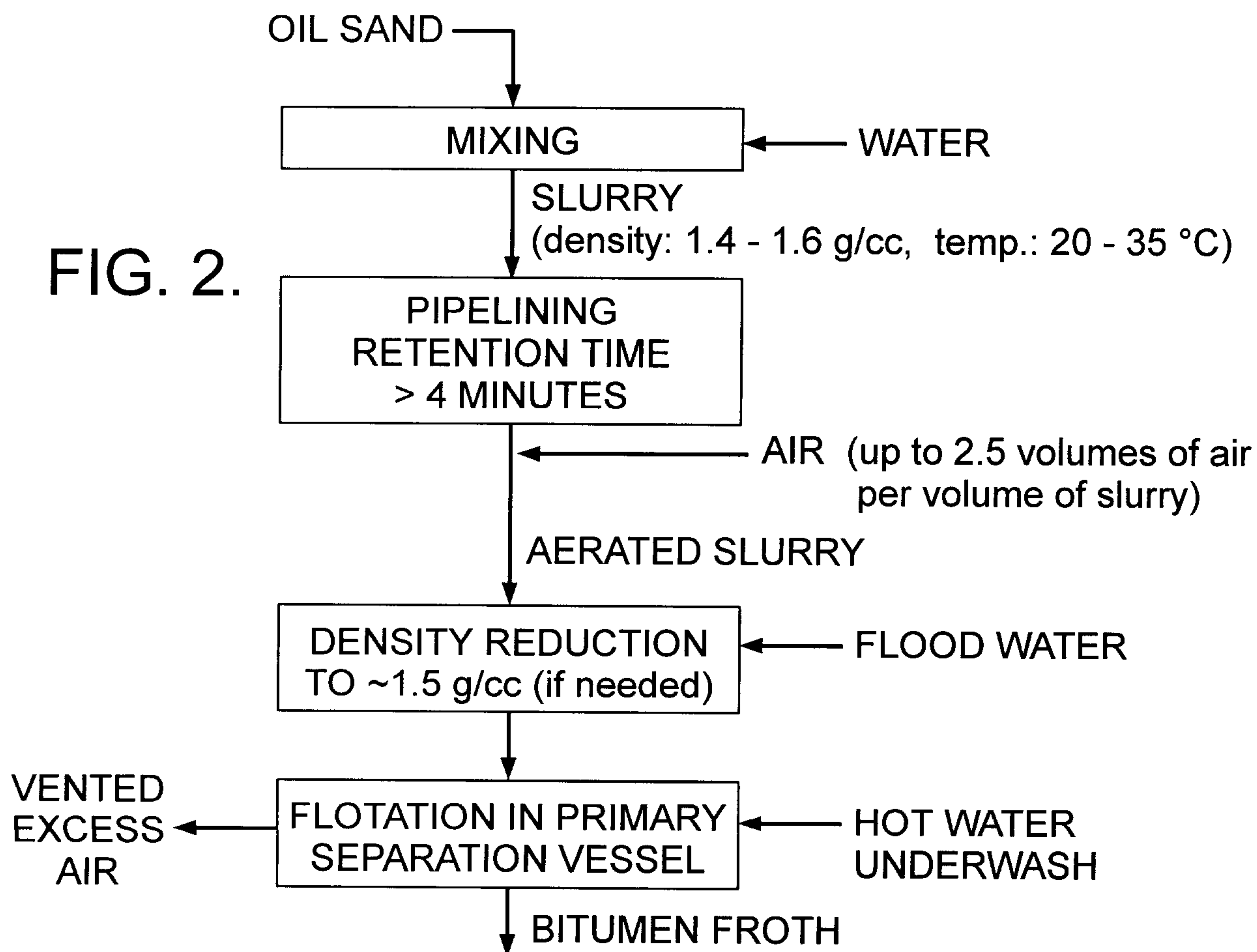


FIG. 2.



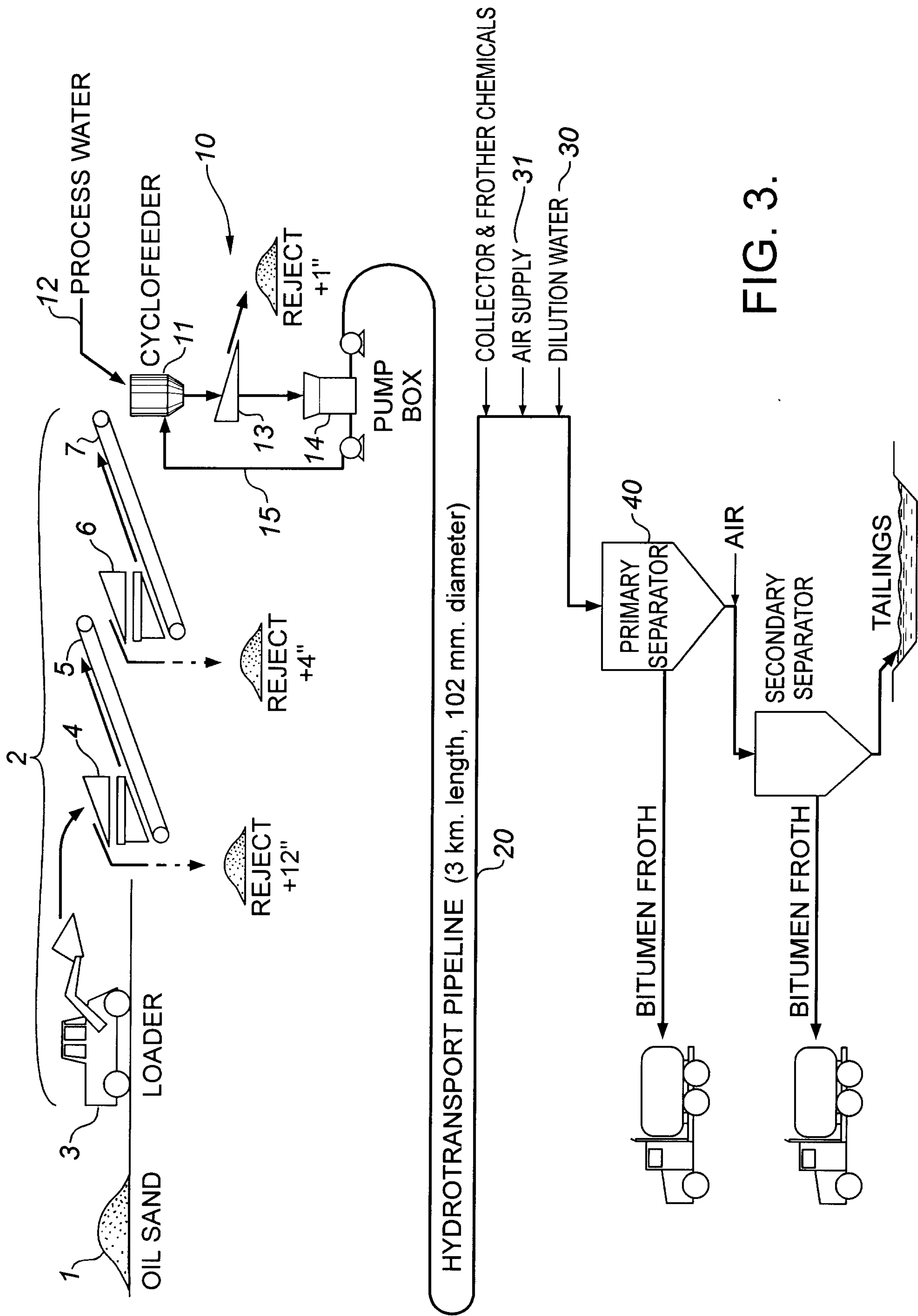


FIG. 3.

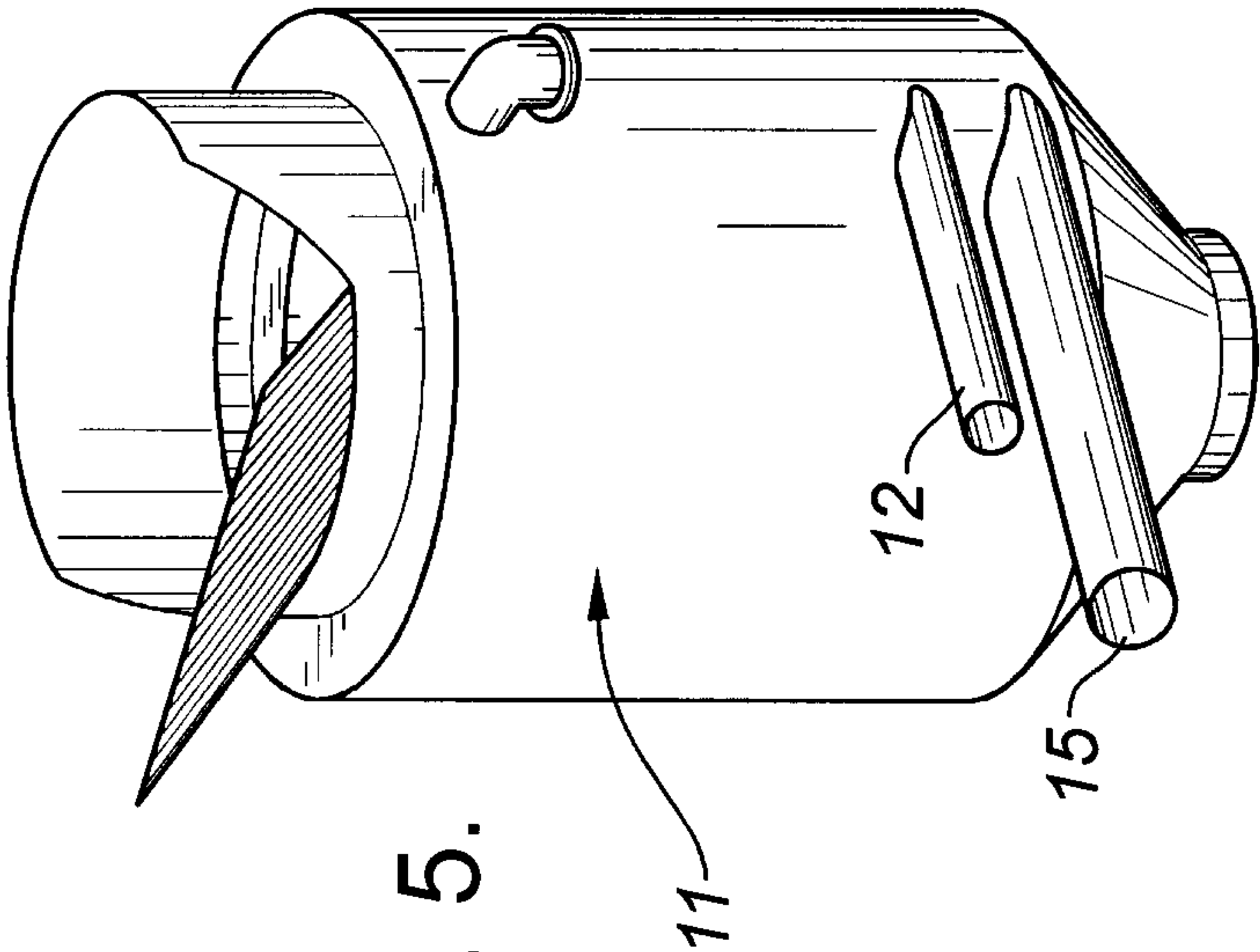


FIG. 5.

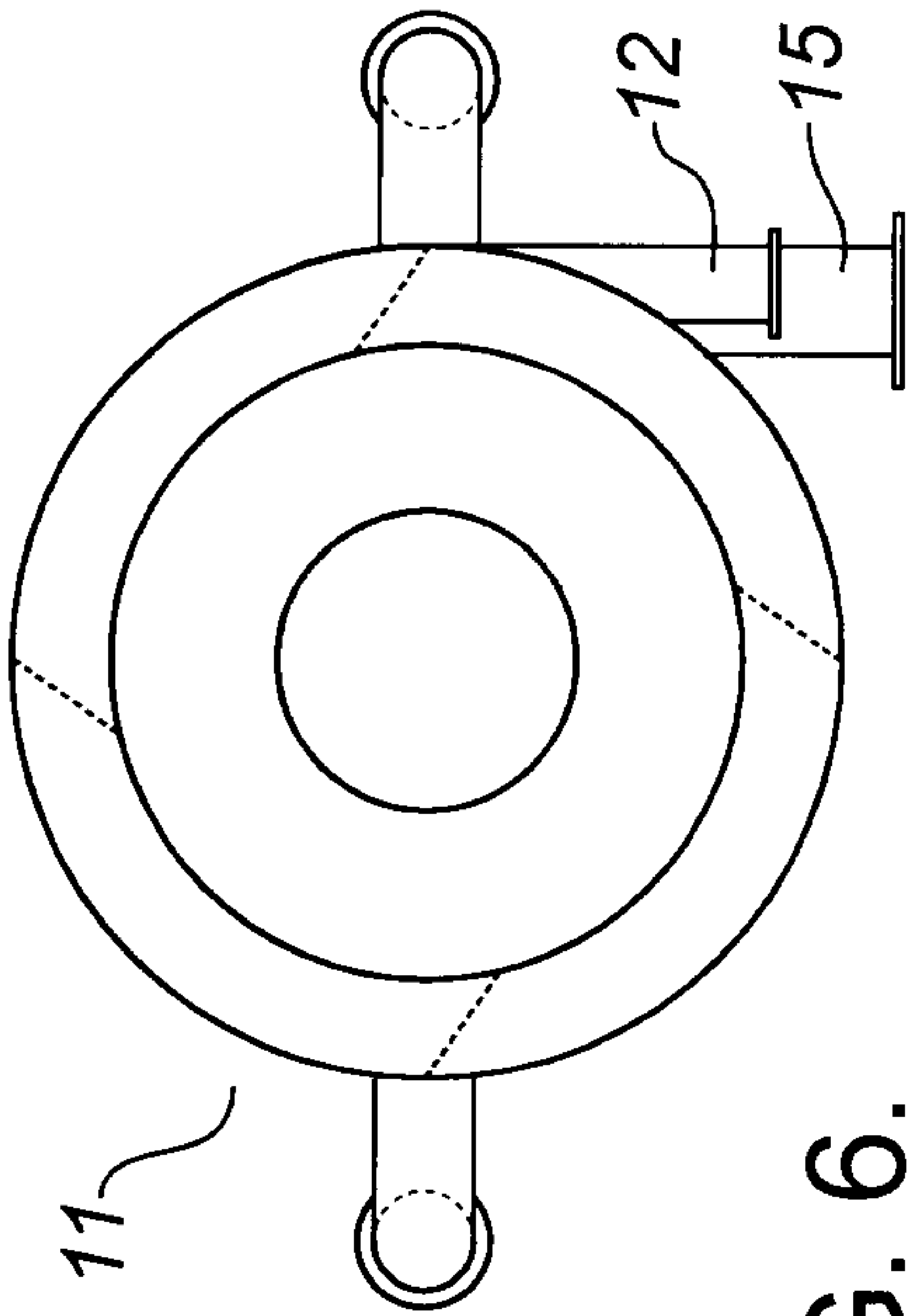


FIG. 6.

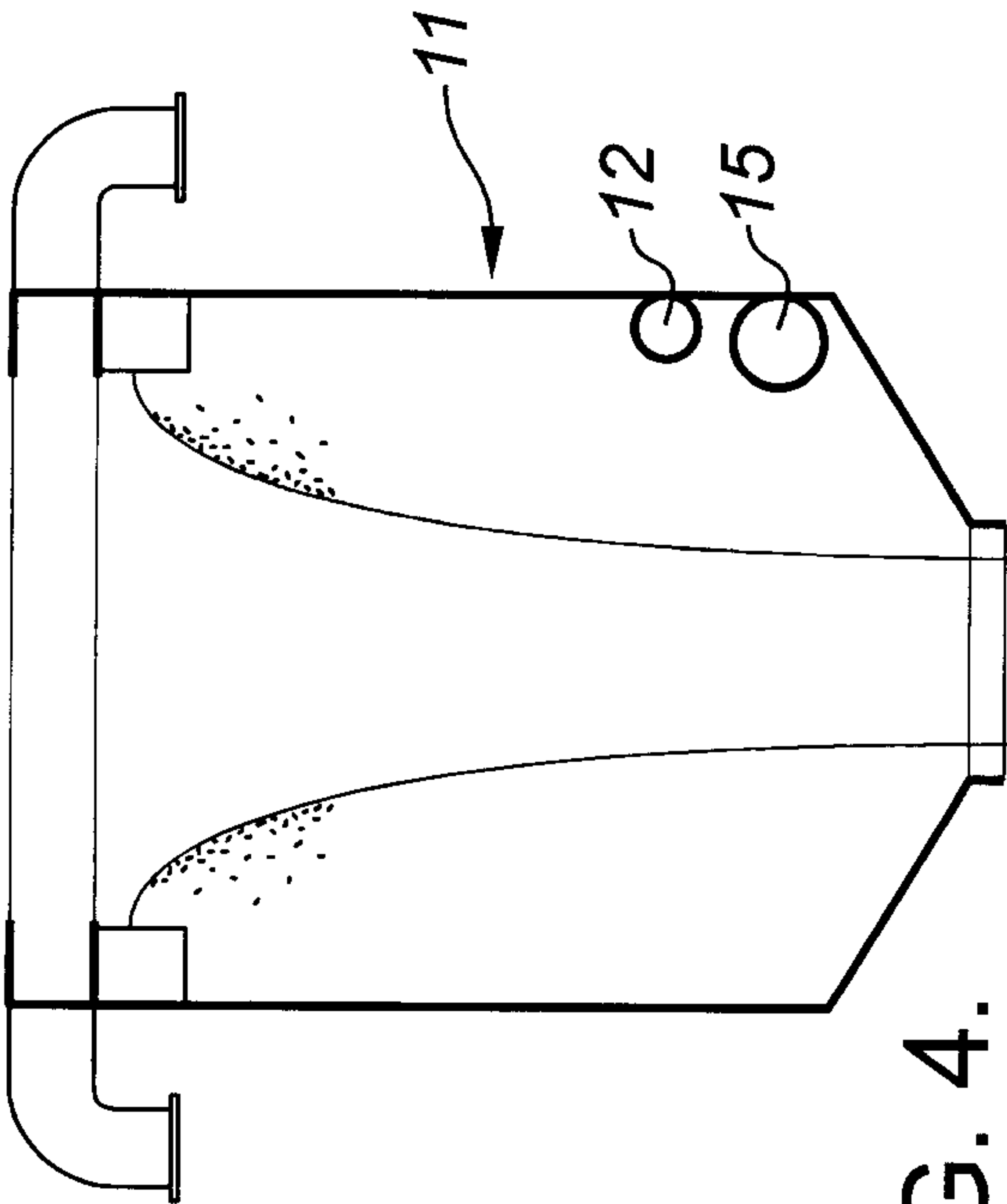


FIG. 4.

4/12

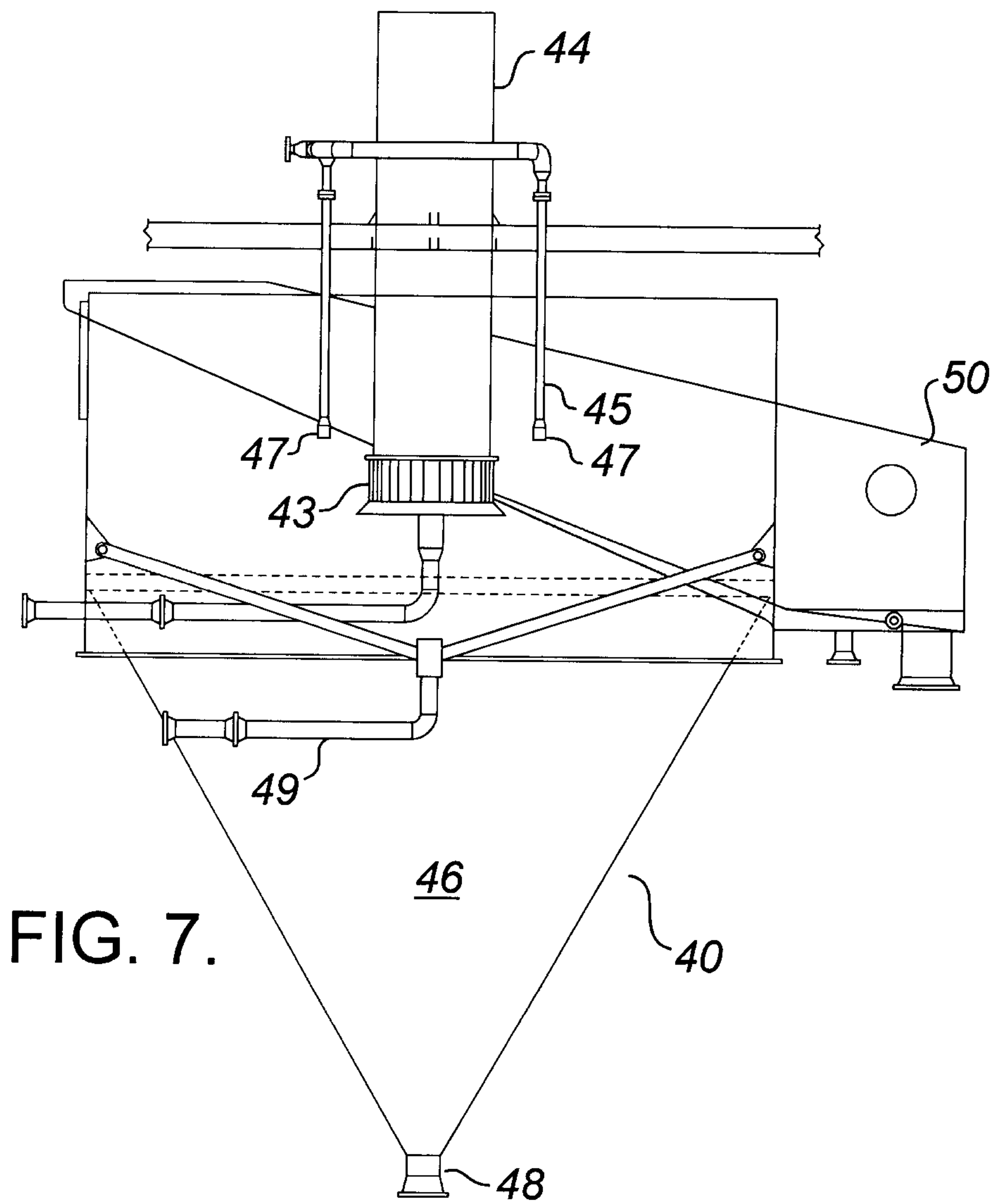
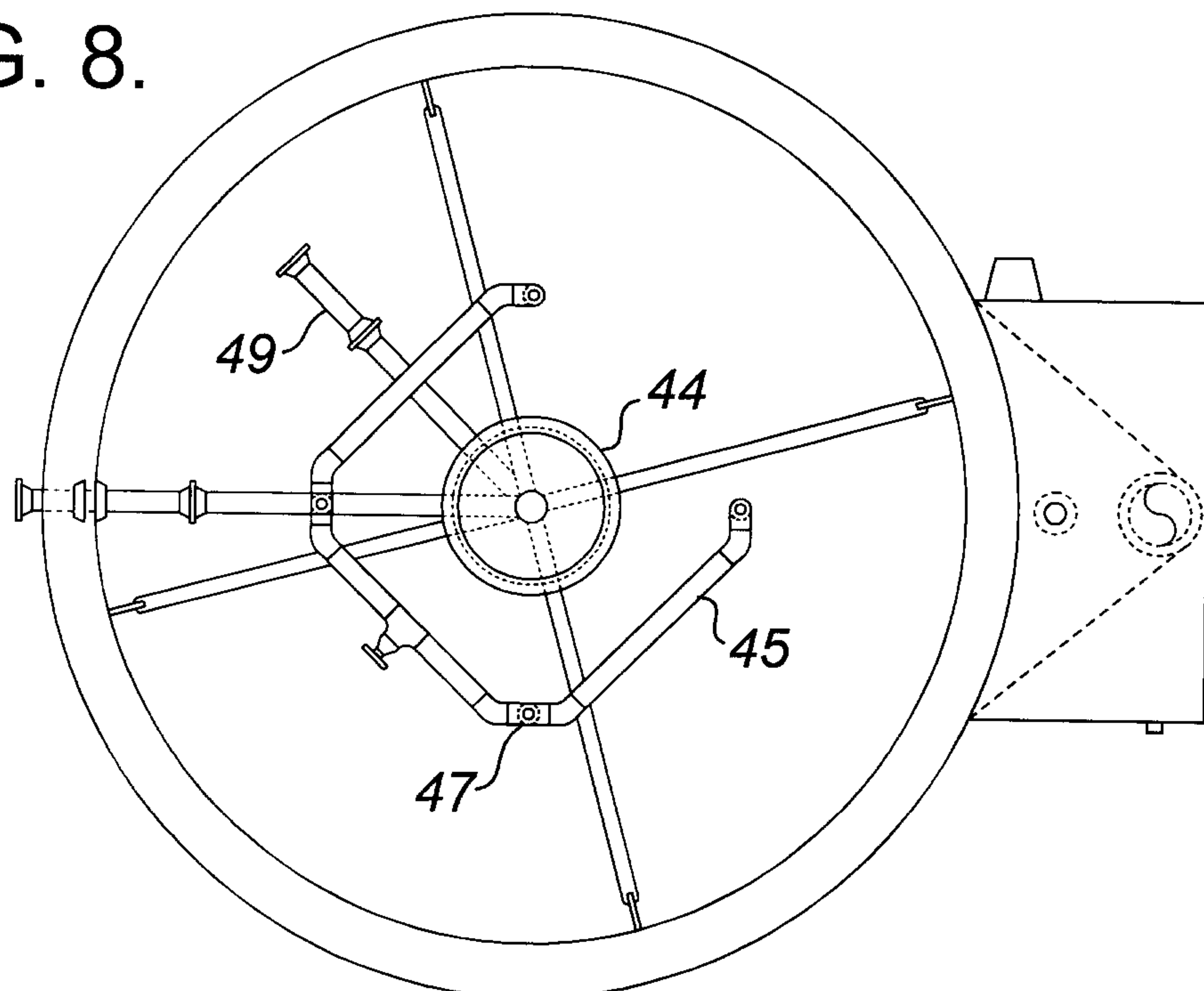


FIG. 8.



5/12

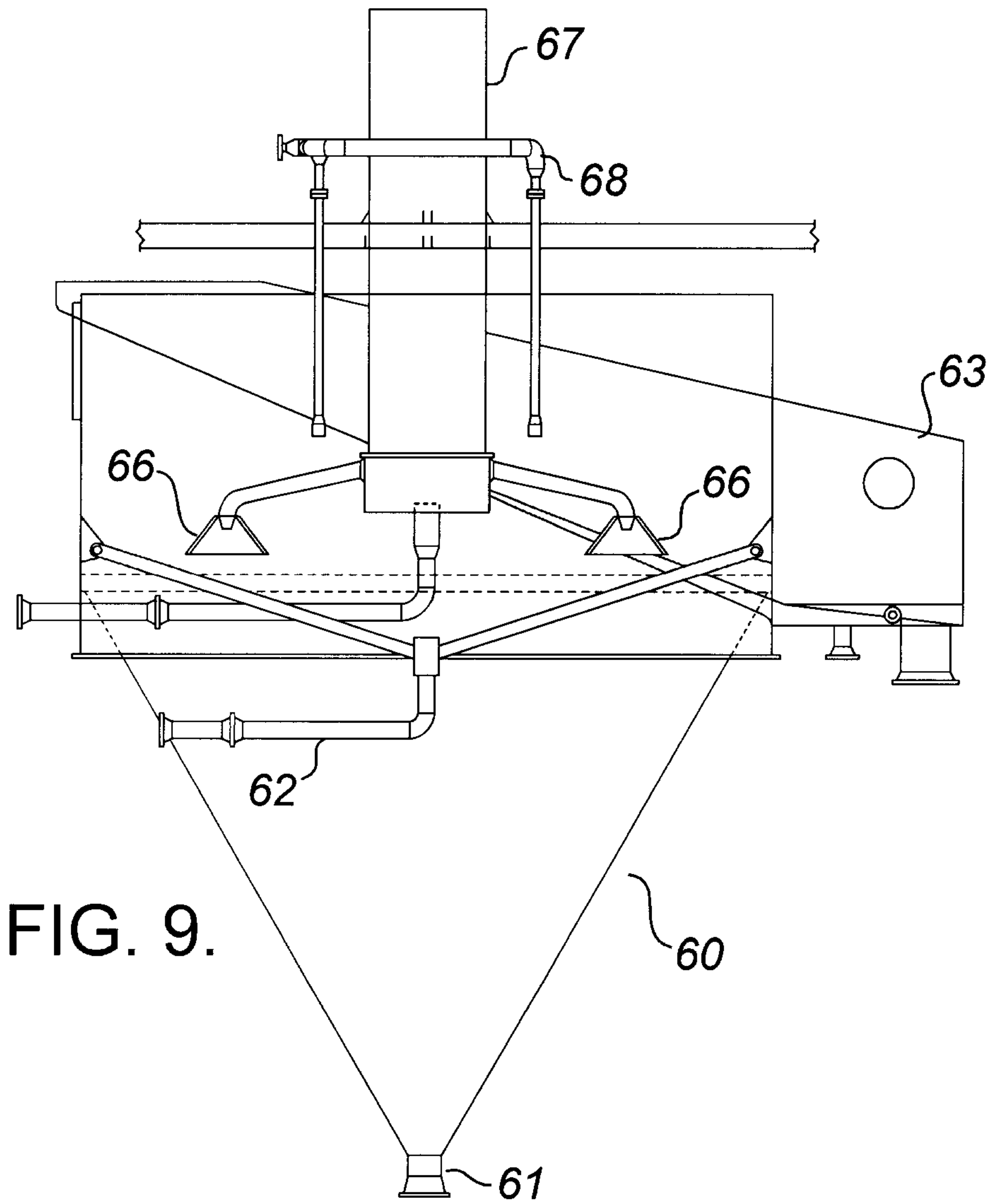
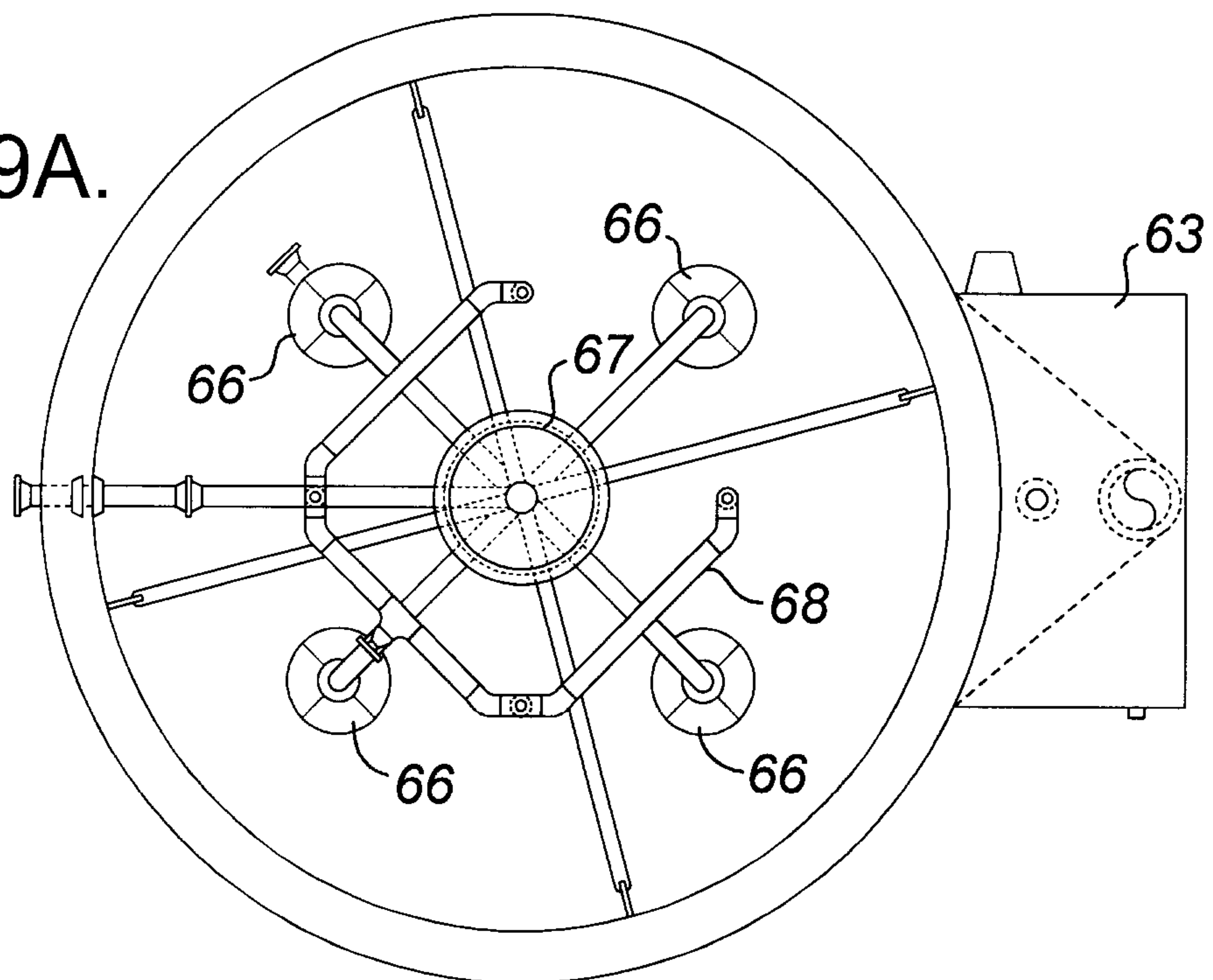


FIG. 9A.



6/12

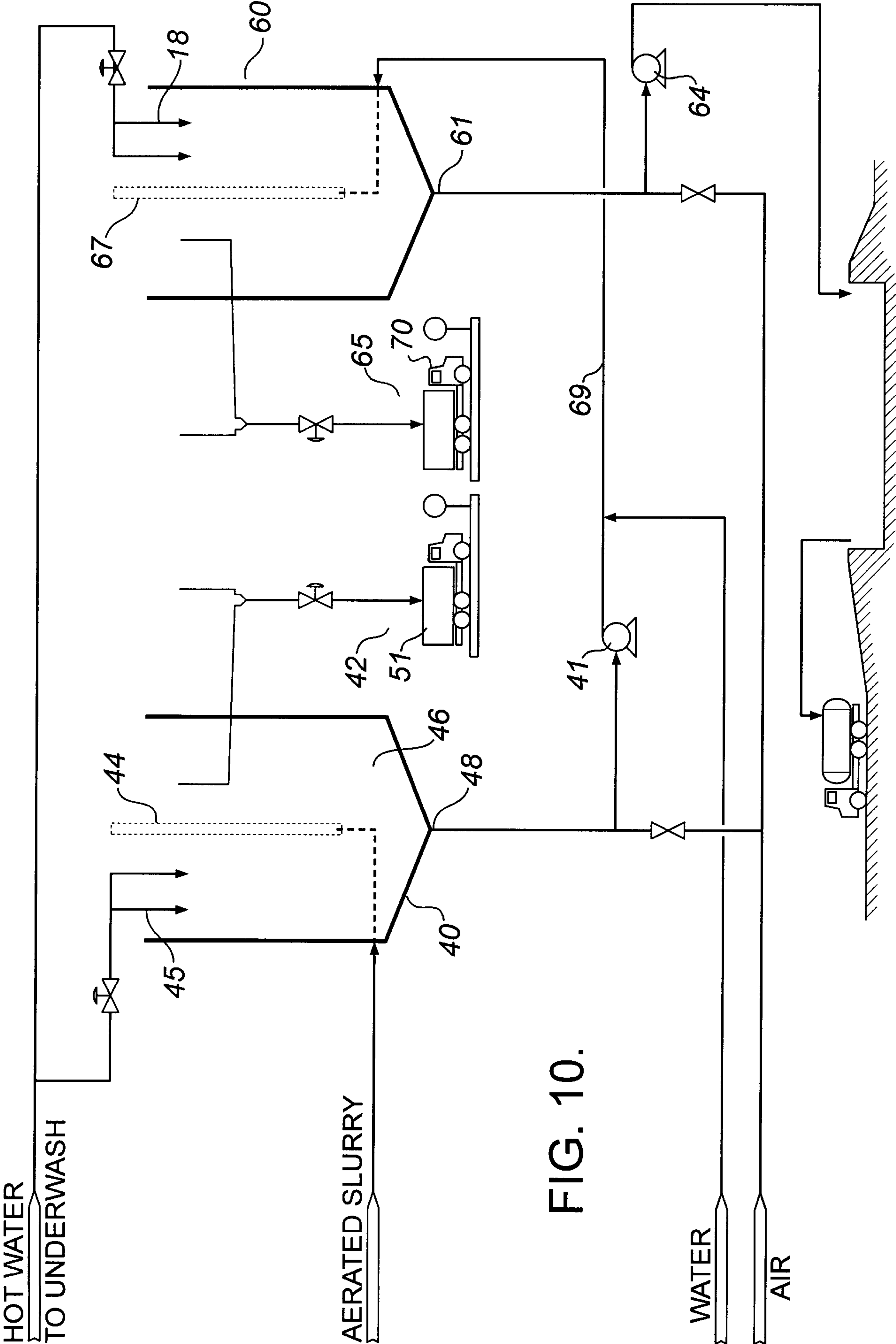


FIG. 10.

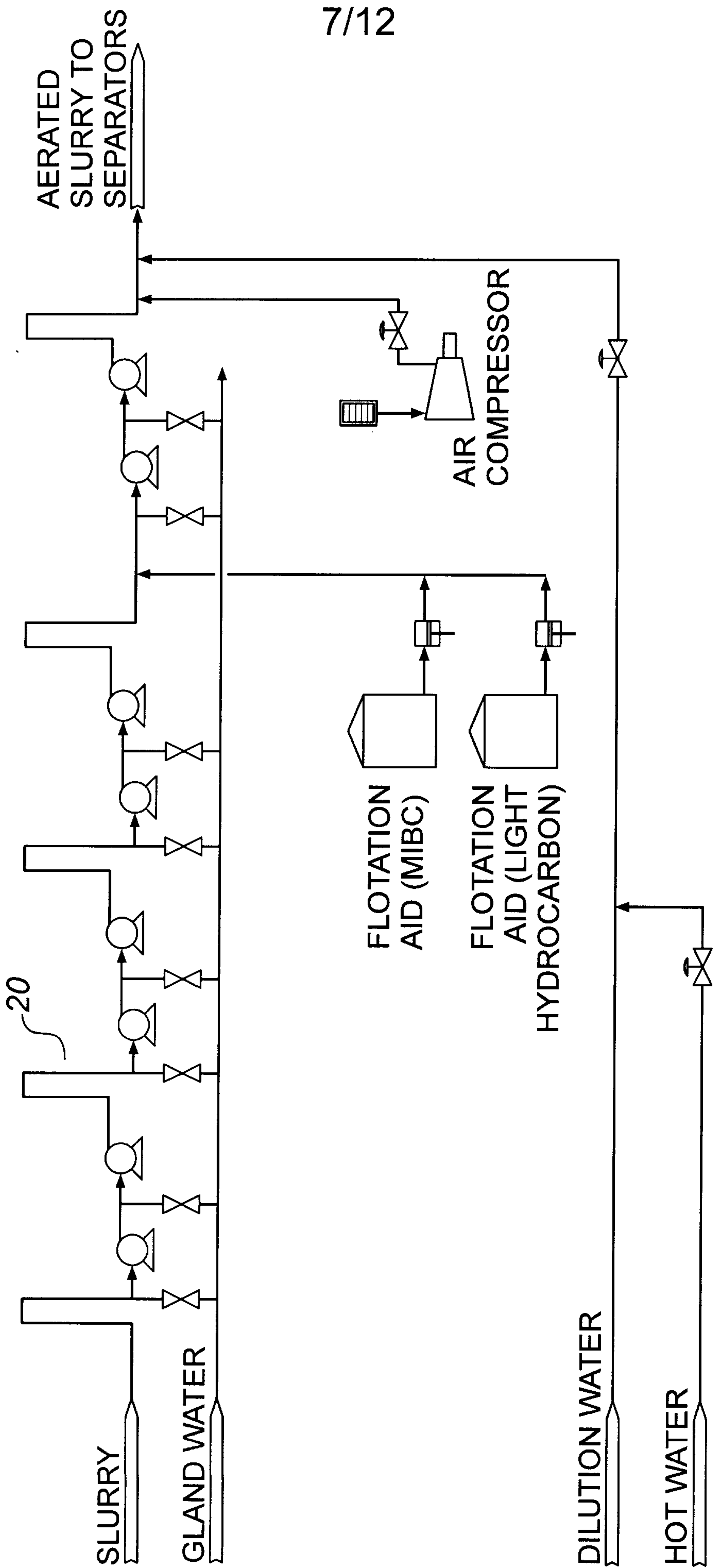
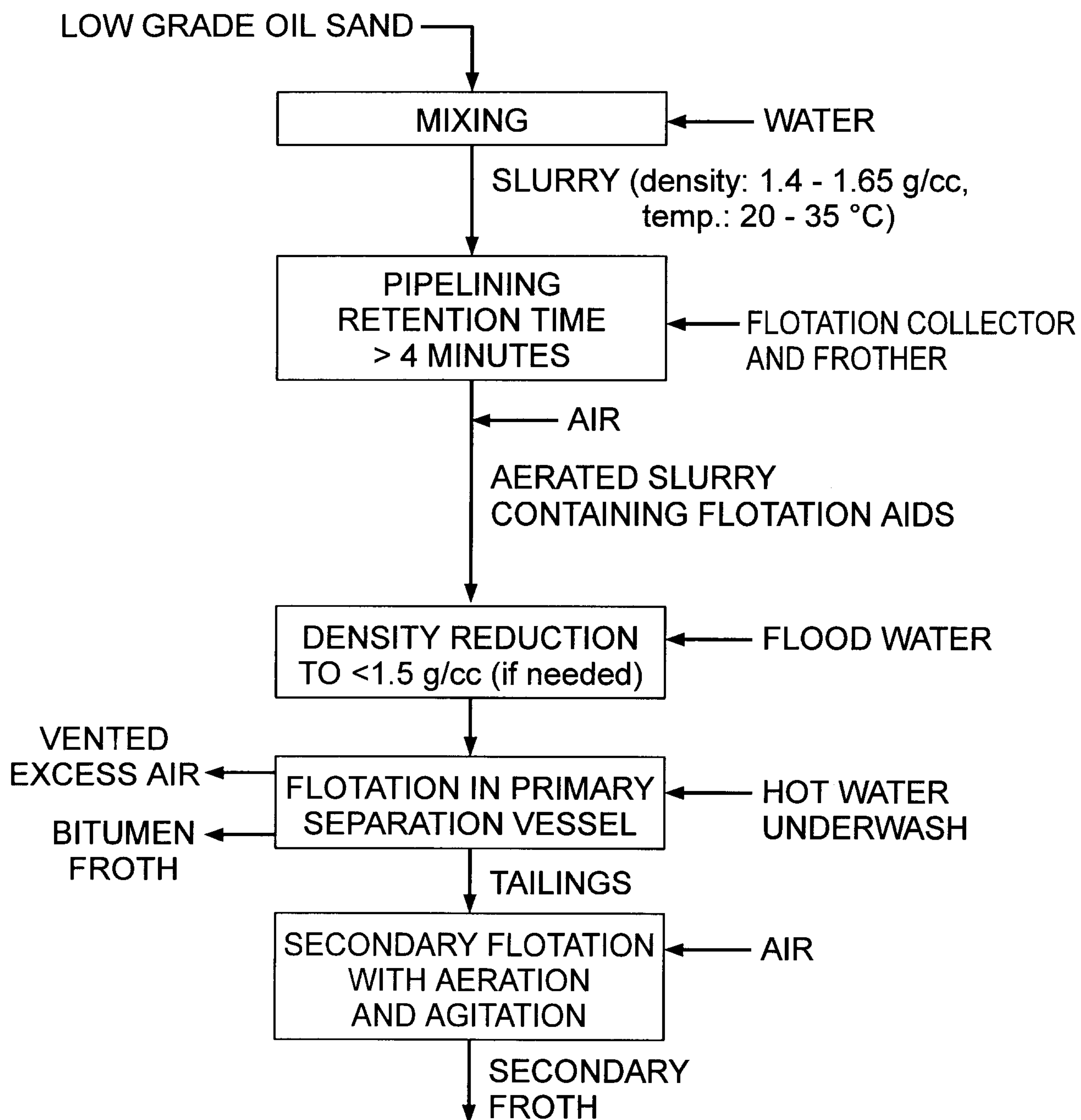


FIG. 11.

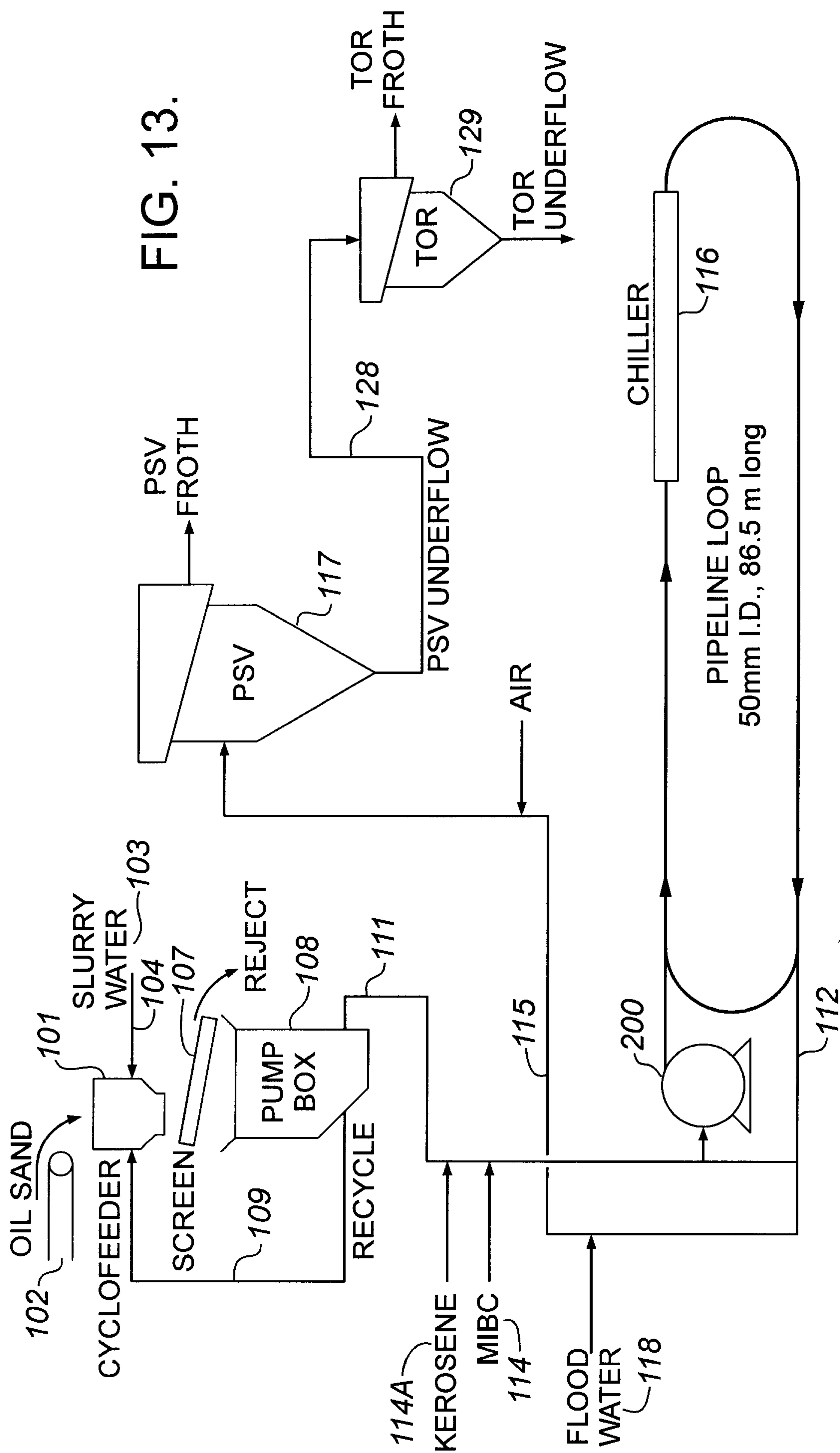
8/12

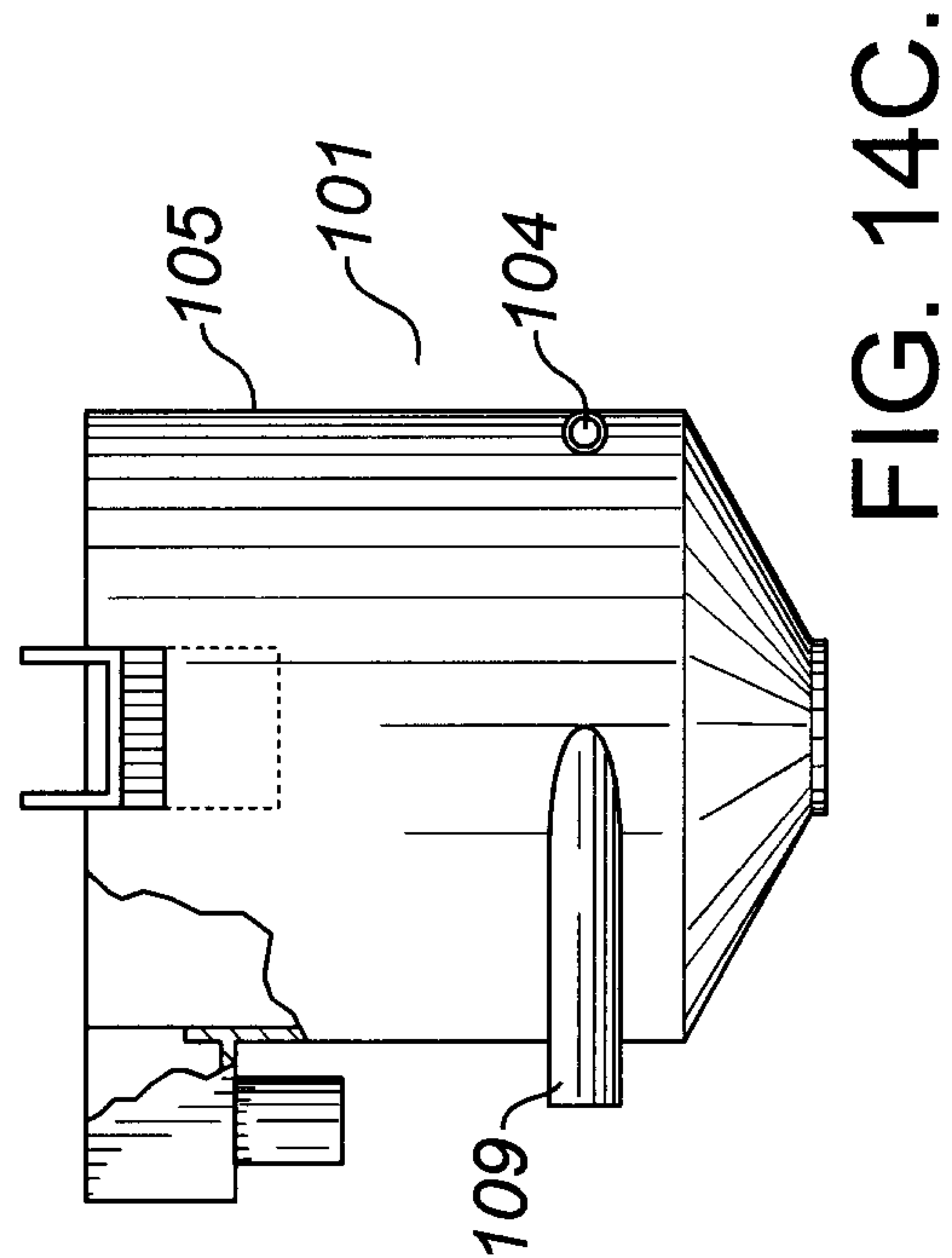
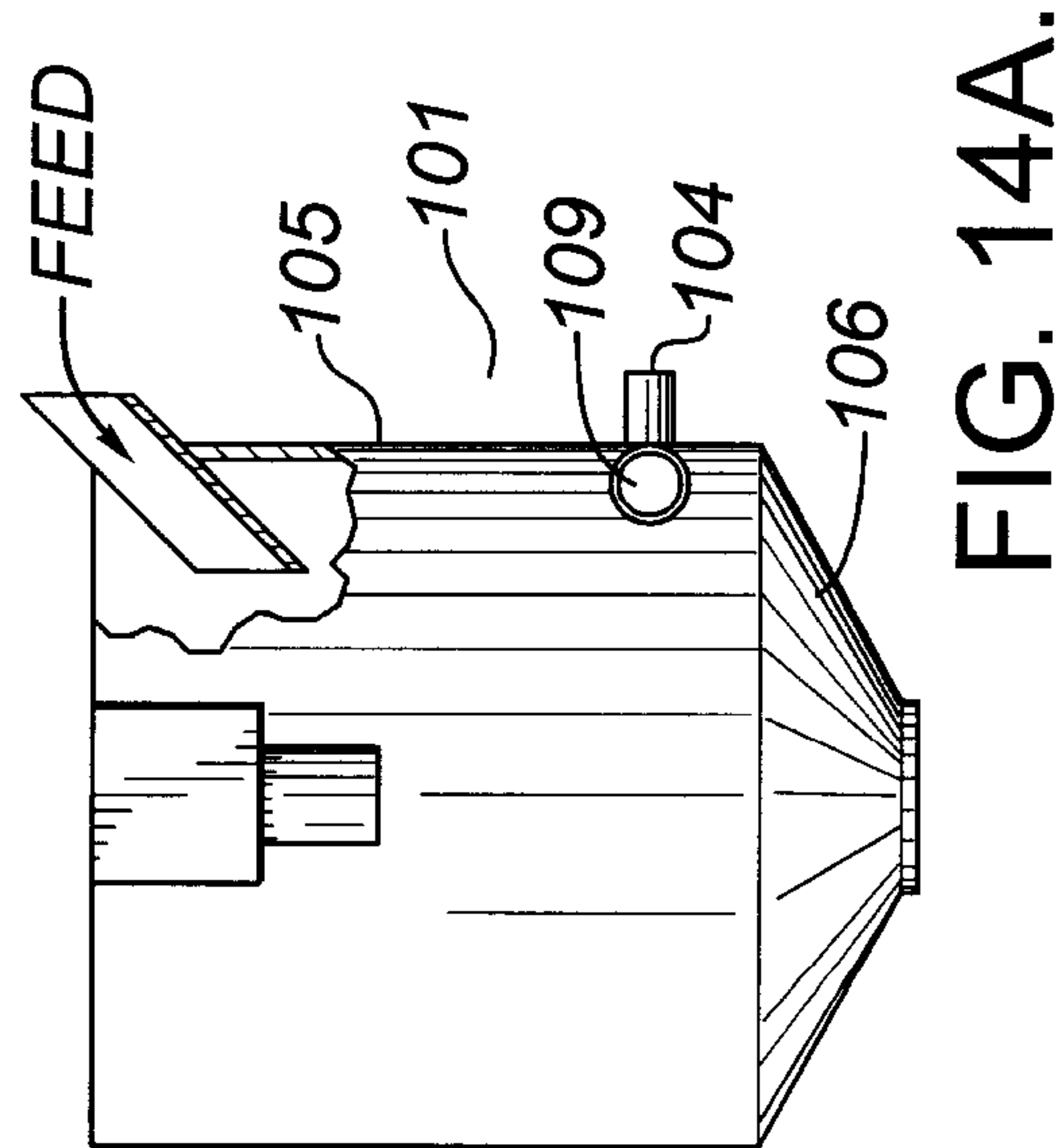
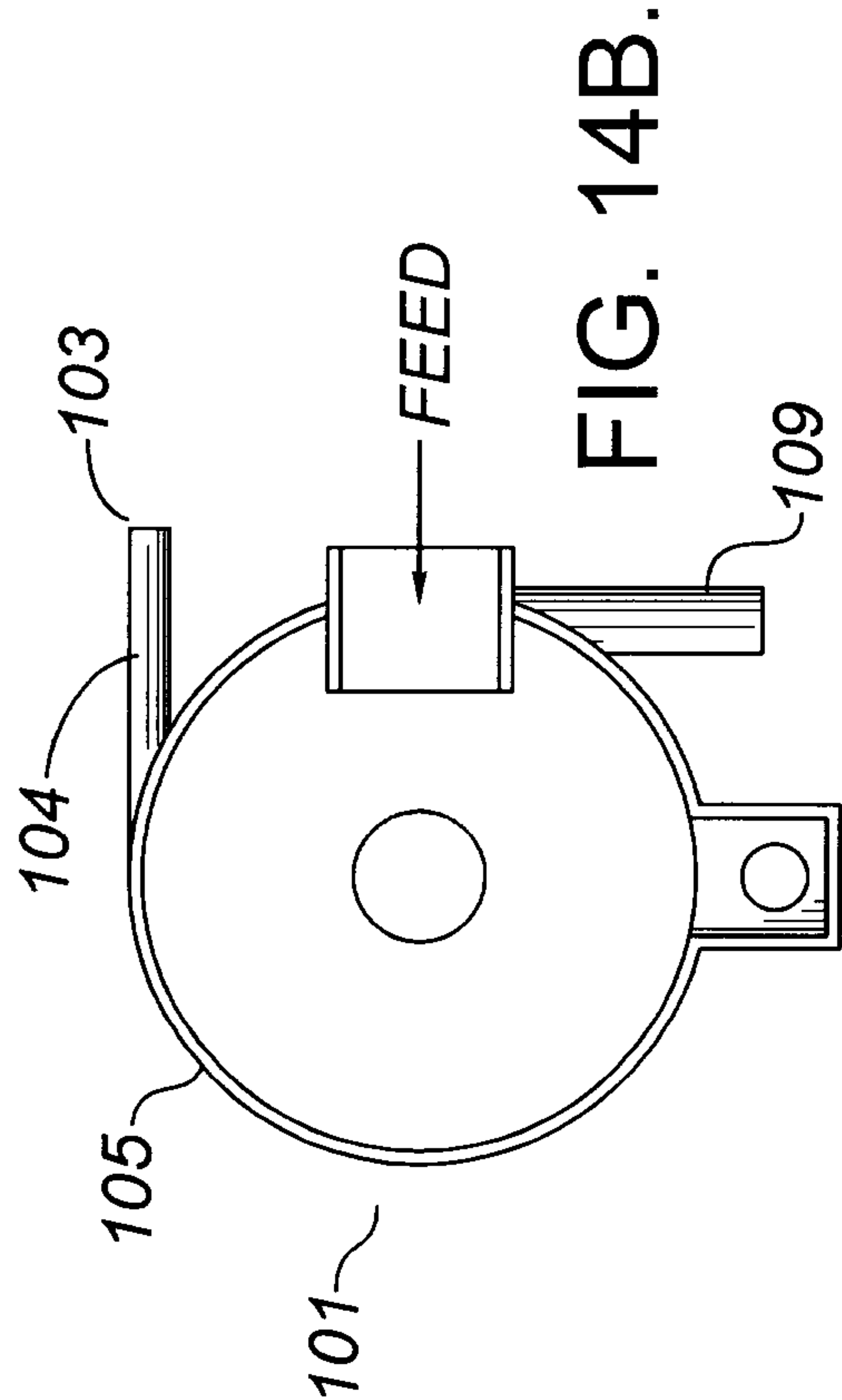
FIG. 12.



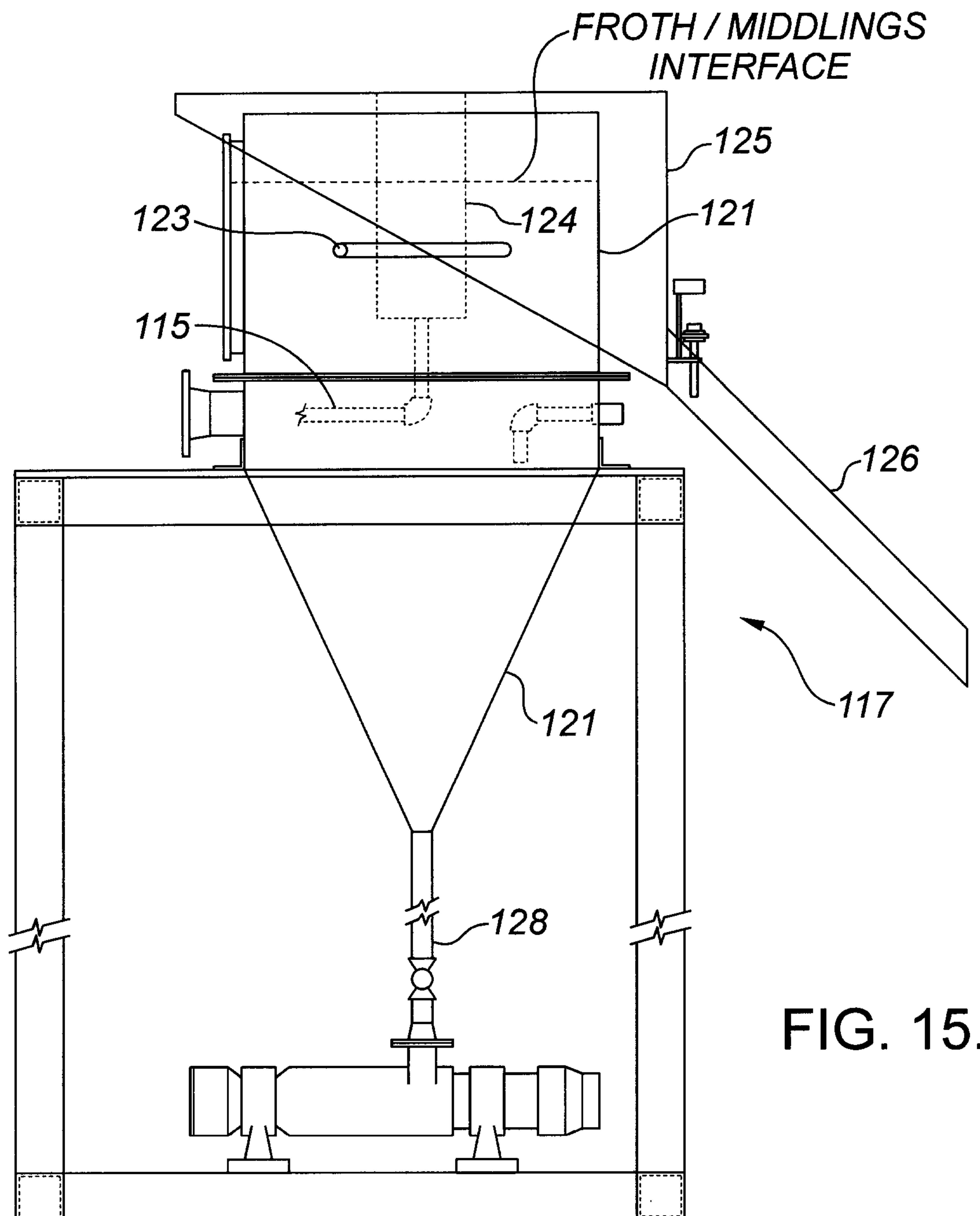
9/12

FIG. 13.





11/12



12/12

FIG. 16.

