

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

- 1 -

DRY CLEANING PROCESS USING ROTATING BASKET AGITATIONField of the Invention

The present invention relates to dry cleaning processes
5 in general and, more particularly, to a dry cleaning process
and system utilizing a solvent and having a rotatable
container for agitating articles.

Background of the Invention

10 Existing dry cleaning processes function by mechanically
agitating articles to be cleaned, e.g., clothes, and a solvent.

Typically, articles of clothing are placed in a container or
basket with an amount of a chemical solvent that loosens dirt
and dissolves staining matter from the clothes. The clothes
15 are then agitated by movement of the basket to increase the
effectiveness of the cleaning process. The agitation is often
in the form of rotation, and rotation with an axis in the
horizontal plane makes use of gravitational forces to further
increase the amount of agitation.

20 Many chemical solvents are environmentally hazardous and
present public health and safety risks. As a result, a number
of solvents have been banned by law or heavily regulated. In
addition, "environmentally friendly" alternatives have been
sought. One such alternative is using liquid carbon dioxide
25 (CO₂) as a solvent.

Dry cleaning systems and processes using
liquid/supercritical dense-phase gas such as carbon dioxide
(CO₂) are known in the art. In such processes, liquid CO₂ is
pumped throughout the system using a heavy-duty positive
30 displacement pump. Specifically, liquid CO₂ is pumped from a
reservoir into a cleaning chamber where articles come into

- 2 -

contact with the CO₂. The articles are cleaned by agitation, such as by rotation of a container holding the articles, and finally, the liquid CO₂ is pumped back into the reservoir. The pump is also used during additional steps of the dry cleaning process as are known in the art.

The use of such a pump has a number of disadvantages that render prior art systems complex and/or cost-inefficient for many applications. One disadvantage is that the pump is a relatively expensive element of the dry cleaning system.

Another disadvantage is that the pump requires a net positive suction head ("NPSH"). This head is generated by both the fluid level in whatever vessel is to be drained and the elevation of the vessel relative to the pump inlet. Configurations that provide adequate pressure such as tall vessels or mounting the vessel about the pump are not desirable because they result in a large machine. Furthermore, completely draining the cleaning chamber still may be difficult because NPSH decreases as the chamber empties.

Another method of providing adequate pump head is by using a distillation chamber. Gas is heated in the chamber, and the resultant pressure increase is used to provide the desired NPSH. However, the use of such a distillation chamber adds complexity and cost to the system.

Furthermore, the pump is susceptible to damage and wear from dirt suspended in the fluid, which reduces the pumping efficiency. Filters cannot be used on the suction side of the pump because they decrease the pressure at the pump inlet, adding to the problem of attaining adequate positive pressure head. Thus, in addition to equipment and operating costs, frequent maintenance is also necessary.

- 3 -

Summary of the Invention

It is an object of the present invention to provide a process and a system for efficiently supplying and/or recycling liquid carbon dioxide (CO₂) in a dry cleaning system using a rotating basket. In accordance with the process of the present invention, pressurized liquid CO₂ is transported between a storage tank and cleaning chamber by means of a pressure differential produced between the tank and chamber, obviating the need for a pump. This eliminates the disadvantages typically associated with such pumps, such as high equipment cost, maintenance downtime and costs due to wear and low efficiency and, thus, expands the circumstances in which the present invention may be used.

In an embodiment of the present invention, the pressure differential is produced by a gas compressor which does not directly interact with liquid CO₂ and, thus, does not accumulate dirt suspended in the liquid CO₂. This eliminates the problems associated with pumps used by prior art systems, making the system of the present invention more cost effective and reliable. The compressor draws gaseous CO₂ from the cleaning chamber and injects it into the storage tank, or vice versa, to create either a positive or a negative pressure differential, respectively, between the storage tank and the cleaning chamber. A positive pressure differential enables flow of liquid CO₂ from the storage tank to the cleaning chamber. A negative pressure differential enables flow of liquid CO₂ from the cleaning chamber to the storage tank. The magnitude of the pressure differential may be controlled by varying the speed of the compressor motor or using a throttle valve.

- 4 -

The dry cleaning process of the present invention may also include a method of recovering heat from the compressed gas. In a vapor recovery step of the dry cleaning process, as described below, heat from the gaseous CO₂ is transferred to a heat sink, which may be in the form of heat exchanger immersed in a water bath, before cooling the CO₂ by a refrigeration system. This reduces the amount of energy consumed by the refrigeration system. The heat energy stored in the heat sink may subsequently be used to heat cold gas during a cleaning chamber warm-up step of the dry cleaning process, as described below, obviating or reducing the need for additional heating. Thus, the present invention utilizes a heat recovery cycle which improves the cost-efficiency of the dry cleaning process.

Except for specific aspects of the present invention, as described herein, the process and system of the present invention are compatible with existing dry cleaning processes and systems and may be used in conjunction with any cleaning chambers and/or baskets and/or other parts of dry cleaning systems that are known in the art.

A dry-cleaning system in accordance with an embodiment of the present invention includes a storage tank for storing CO₂ at a selectable pressure, a cleaning chamber having a pressure containment sufficient to keep CO₂ in a liquid state, means for providing a pressure differential between the storage tank and cleaning chamber, a rotatable basket within the cleaning chamber, and a rotational drive mechanism coupled to the basket. In some embodiments of the invention, the system may further include a vapor heat exchanger/recovery system, a refrigeration system, a lint trap/filtration system, and a cleaning chamber ventilation

- 5 -

system. The pressure differential between the storage tank and cleaning chamber may be produced by a gas compressor, which may be an oil-less compressor.

5 A dry cleaning process in accordance with an embodiment of the present invention may include at least some of the following steps:

(a) Removing moisture-laden air from the cleaning vessel. The compressor may act as a vacuum pump to evacuate the air to the atmosphere.

10 (b) Equalizing pressure between the storage tank and the cleaning chamber in a controlled fashion to avoid clothes damage. CO₂ gas may flow from the comparatively higher pressure storage tanks to the comparatively lower pressure cleaning chamber until a predetermined pressure difference
15 exists between the cleaning chamber and the storage tank.

(c) Filling the cleaning chamber with a predetermined amount of liquid CO₂ from the storage tank. CO₂ vapor may be drawn from the top of the cleaning chamber by the compressor and moved into the top of the storage tank, creating a
20 pressure differential forcing liquid to flow from the bottom of the tank into the cleaning vessel.

(d) Agitating the articles being cleaned by rotating the basket.

(e) Draining used/contaminated liquid from the cleaning
25 chamber. CO₂ vapor may be drawn from the top of the storage tank by the compressor and moved into the top of the cleaning chamber, creating a pressure differential forcing liquid from the bottom of the chamber into the bottom of the storage tank. The liquid may pass through a filter system located
30 between the vessels.

- 6 -

(f) Recovering CO₂ vapor remaining in the cleaning chamber after drainage. CO₂ vapor may be drawn from the top of the cleaning chamber and pushed by the compressor, through a heat recovery system and/or refrigeration system that cools and condenses the vapor into liquid and into the storage tank.

(g) Heating the cleaning chamber. CO₂ vapor may be drawn from the top of the cleaning chamber and pushed by the compressor through a heat exchanger system that heats the vapor and into the bottom of the cleaning chamber.

(h) Venting the cleaning chamber. CO₂ vapor may flow out of the cleaning chamber through a cleaning chamber ventilation system, which may include a sound control muffler.

15

Brief Description of the Drawings

The present invention will be understood and appreciated more fully from the following detailed description of a preferred embodiment of the invention, taken in conjunction with the accompanying drawings of which:

20

Fig. 1 is a schematic illustration of a dry-cleaning system during an air evacuation step of a dry-cleaning process in accordance with an embodiment of the present invention;

25

Fig. 2 is a schematic illustration of the system of Fig.1 during a pressure equalization step of a dry-cleaning process in accordance with an embodiment of the present invention;

30

Fig. 3 is a schematic illustration of the system of Fig.1 during cleaning chamber filling and agitation steps of

- 7 -

a dry-cleaning process in accordance with an embodiment of the present invention;

Fig. 4 is a schematic illustration of the system of Fig.1 during a cleaning chamber draining step of a dry-cleaning process in accordance with an embodiment of the present invention;

Fig. 5 is a schematic illustration of the system of Fig.1 during a cleaning chamber vapor recovery step of a dry-cleaning process in accordance with an embodiment of the present invention;

Fig. 6 is a schematic illustration of the system of Fig.1 during a cleaning chamber warm-up step of a dry-cleaning process in accordance with an embodiment of the present invention;

Fig. 7 is a schematic illustration of the system of Fig.1 during a cleaning chamber ventilation step of a dry-cleaning process in accordance with an embodiment of the present invention; and

Fig. 8 is a schematic graphic representation of a dry cleaning process sequence in accordance with an embodiment of the present invention.

Detailed Description of the Invention

Reference is now made to Figs. 1-7 which schematically illustrate a dry-cleaning system in accordance with an embodiment of the present invention during various stages of a dry-cleaning process in accordance with an embodiment of the present invention. The system includes a cleaning chamber 10, for example an about 80-gallon cleaning chamber, having a basket 12 for holding articles to be cleaned. Cleaning chamber 10 is preferably designed to have high

- 8 -

pressure containment capability, for example, a pressure containment of about 1,100 PSI, sufficient to maintain carbon dioxide (CO₂) in a liquid state.

Basket 12 is rotatably mounted within cleaning chamber 10 and is coupled to a basket drive 14 via a coupling 16, which may be of any type suitable for maintaining pressure integrity of cleaning chamber 10, for example, a mechanical coupling with a high-pressure seal, as is known in the art.

However, in a preferred embodiment of the invention, coupling 16 is a magnetic coupling which eliminates the need for an opening in chamber 10, as required in the case of mechanical coupling. Rotational driving mechanism using magnetic coupling are well known in the art and are known in the art.

The system further includes at least one storage tank 20 having a predetermined volume capacity, for example, about 30-50 gallons. Storage tank 20 preferably has high pressure containment capability, for example, about 1,100 PSI, and is filled with a predetermined initial amount of CO₂, for example, 100 gallons.

In a preferred embodiment of the invention, the system also includes a lint trap/filtration system comprising a lint trap 24, for example, a 100 mesh lint trap, as is known in the art, and a filter 26, for example, a 40 micron filter, as is known in the art.

In accordance with the present invention, the system includes means for providing a pressure differential between storage tank 20 and cleaning chamber 10 that comprises a gas compressor 30, preferably an oil-less compressor. An important advantage of using a gas compressor such as compressor 30, rather than a liquid pump (as used in prior

- 9 -

art systems), is that gas flow does not suspend dirt and, thus, dirt is not carried into the compressor. This reduces wear and, consequently, operating and maintenance costs of the dry cleaning system.

5 Compressor 30 is preferably capable of producing partial vacuum duty and vapor recovery. In an embodiment of the present invention, compressor 30 is capable of decreasing the pressure in cleaning chamber 10 to less than 400 PSI, preferably less than 150 PSI, for example about 50 PSI. It
10 should be appreciated that a low pressure in chamber 10 minimizes wastage of CO₂ during venting of the cleaning chamber, as described below. Further, in an embodiment of the present invention, compressor 30 is capable of increasing the pressure in storage tank 20 to more than 750 PSI, preferably
15 more than 850, for example, 900 PSI. It should be appreciated that a high pressure in storage tank 20 maintains the CO₂ in liquid state with minimal cooling and, therefore, enables more energy-efficient dry cleaning. The magnitude of the pressure differential produced between storage tank
20 20 and cleaning chamber 10 may be controlled by varying the motor speed of compressor 30 or using a throttle valve, as is known in the art. An example of an oil-less compressor that may be used in conjunction with the present invention to provide the above described parameters is the Blackmer HDL
25 322 oil-less compressor, available from Blackmer, Inc., Oklahoma City, Oklahoma.

The system preferably further includes a heat exchanger/recovery system 31 comprising a heat sink/water bath 28 and associated heat exchanger 32 in the embodiment
30 shown. Heat recovery system 31 collects heat energy from hot gas in one step of the dry cleaning process and utilizes that

- 10 -

heat energy to warm cold gas during another step, as is described below. Heat energy may be transferred to water bath 28 from CO₂ passing through heat exchanger 32 at certain times during the dry cleaning cycle, and water bath 28 may
5 transfer heat to CO₂ at other times during the cycle. Preferably, an electric heater 40 is installed in water bath 28 to maintain it at a predetermined temperature, for example, 80°C, during idle periods of the dry-cleaning process.

10 In an embodiment of the present invention, a refrigeration system 35 with a heat exchanger 36 adapted for cooling CO₂ is included. Preferably, refrigeration system 35 possesses sufficient cooling capacity to condense CO₂ passing through heat exchanger 36.

15 As clearly shown in the drawings but not individually referenced, the dry cleaning system includes piping as necessary for connecting between the different system elements of the system and various valves for controlling the operation of the system and CO₂ flow during different steps
20 of the dry cleaning process. Some of these valves are specifically discussed below with reference to steps of the dry cleaning method of the present invention. However, the function of most of these valves will be apparent to persons of ordinary skill in the art of dry-cleaning systems. The
25 system further includes a cleaning chamber ventilation system 41 with, preferably, a sound control muffler 46 that may be used during final venting of cleaning chamber 10, as described below.

30 Reference is now made also to Fig. 8 that schematically illustrates the different steps of a dry cleaning process according to an embodiment of the present invention and shows

- 11 -

an exemplary duration for each step. Fig. 8 is self-explanatory to a person skilled in the art. A detailed description of the different steps of the dry cleaning according to an embodiment of the present invention is provided below with reference to Figs. 1-7.

Fig. 1 illustrates an air evacuation step of the dry-cleaning process in accordance with an embodiment of the present invention. The purpose of this step is to remove moisture laden air, thus reducing the amount of water that dissolves in the CO₂. Compressor 30 acts as a vacuum pump with respect to cleaning chamber 10. Compressor 30 is activated for a predetermined time period, for example, about 2 minutes, until a predetermined pressure is reached, for example, 20-25 inches Hg, as determined by a pressure transducer 42. Once the desired pressure level is reached, compressor 30 is shut down.

Fig. 2 schematically illustrates a pressure equalization step of the dry-cleaning process in accordance with an embodiment of the present invention. During this step, the pressure between storage tank 20 and cleaning chamber 10 is generally equalized in a controlled fashion to avoid damage to the articles being cleaned. Gaseous CO₂ flows from the top of storage tank 20 to the top of cleaning chamber 10 through a valve 44 and an orifice 47 until the difference between the readings of pressure transducer 42 and a pressure transducer 48 in the storage tank 10 is below a predetermined threshold, for example a 10 percent pressure differential.

Fig. 3 schematically illustrates a step of partially filling cleaning chamber 10 with liquid CO₂ from storage tank 20. Gaseous CO₂ is drawn from a top opening 18 of cleaning chamber 10 and is pushed by compressor 30 into the top of

- 12 -

storage tank 20. In this step, compressor 30 produces a positive pressure differential between storage tank 20 and cleaning chamber 10, enabling the flow of liquid CO₂ from the storage tank to the cleaning chamber. Although heating of the CO₂ is not required at this stage of the process, the CO₂ flows through heat exchanger 32 in water bath 28, thus utilizing the same piping scheme for different stages of the process. The flow of gas into storage tank 20 forces liquid CO₂ out of the bottom and into a bottom opening 38 of cleaning chamber 10 until the desired level of liquid CO₂ is reached. This level may be determined by a timer (not shown) and/or by a level sensor 50 associated with storage tank 20.

Also referring to Fig. 3, after filling cleaning chamber 10, the articles within basket 12 may be agitated by rotating the basket. As discussed above, any suitable rotational basket drive 14 may be used. If coupling 16 between basket drive 14 and basket 12 is a mechanical coupling, pressure integrity of cleaning chamber 10 may be maintained by a suitable high pressure seal. In the preferred embodiment, coupling 16 is magnetic so that pressure integrity is not an issue. The basket is agitated for an adequate time to clean the articles located therein, e.g., clothes. The time of the agitation may be dependent upon various factors, including the nature and amount of articles in the cleaning chamber, the composition, temperature and pressure of the solvent, the speed of rotation of basket during agitation, and the configuration of any structures within the basket, e.g., the height of paddles, as is known in the art.

Referring to Fig. 4, after agitation as described above, used/contaminated liquid is removed from cleaning chamber 10.

Gaseous CO₂ is drawn from the top of storage tank 20 and is

- 13 -

pumped by compressor 30 into the top opening 18 of cleaning chamber 10. This forces the used/contaminated liquid CO₂ out of bottom opening 38 of cleaning chamber 10 and into the bottom of storage tank 20. Thus, in this step, compressor
5 30 produces a negative pressure differential between storage tank 20 and cleaning chamber 10, enabling the flow of liquid CO₂ from the cleaning chamber to the storage tank. Preferably, the liquid flows through lint trap 24 and filter 26 before entering storage tank 10. Also, the liquid
10 preferably passes through refrigeration system 35 via its heat exchanger 36, where it is cooled before entering storage tank 10. The flow stops when a level sensor 57 on cleaning chamber 10 indicates it is empty.

Fig. 5 schematically illustrates a vapor pressure
15 recovery step in accordance with an embodiment of the dry-cleaning process of the present invention. This step recovers CO₂ vapor remaining in cleaning chamber 10 after the drainage step described above. Gaseous CO₂ is drawn by compressor from top opening 18 of cleaning chamber 10. The
20 gas exiting compressor 30 is hot and needs to be cooled. The gas is directed first through heat exchanger 32 in water bath 28, where some of the heat energy is transferred to water bath 28 and the CO₂ is somewhat cooled, and then into heat exchanger 36 in refrigeration system 35. This cools and
25 condenses the CO₂ gas back into a liquid state. The liquid CO₂ then flows into storage tank 20. The flow stops when the pressure measured by pressure transducer 42 in cleaning chamber 10 reaches a sufficiently low threshold, for example, 50 psi.

30 Fig. 6 schematically illustrates a cleaning chamber warm-up step of the dry-cleaning process in accordance with

- 14 -

an embodiment of the present invention. This step is implemented to warm up the interior of cleaning chamber 10 and the articles therein, thereby preventing water ice formation during vapor recovery. Cool CO₂ vapor is drawn
5 from top opening 18 of cleaning chamber 10 and is pumped by compressor 30 through heat exchanger 32 in water bath 28, where the CO₂ is heated at least in part by transfer of energy that was stored in water bath 28 during the vapor recovery step. The gas then flows through an opening 58 into
10 the cleaning chamber 10. The heated CO₂ warms-up cleaning chamber 10 and the articles therein. Heating element 40 may be utilized during this step to transfer heat to water bath 28.

In an embodiment of the present invention, the cleaning
15 chamber warm-up is utilized during vapor recovery. Recovery as described above continues until a first predetermined temperature is reached, for example, 35-40°F, as measured by a temperature sensor 55 in cleaning vessel 10. At this point, vapor recovery pauses and warm-up begins and continues
20 until a second predetermined temperature is reached, for example, a temperature greater than 50°F, which may also be measured by sensor 55. Thereafter, vapor recovery is resumed. For example, the dry-cleaning process summarized in Fig. 10 includes two vapor recovery steps, 3 minutes and
25 5 minutes, respectively, with an interceding two minute warm-up step.

Fig. 7 schematically illustrates a cleaning chamber venting step of the dry-cleaning process in accordance with an embodiment of the present invention. Remaining CO₂ vapor
30 within cleaning chamber 10, which may be at about 50 psi, is vented through cleaning chamber ventilation system 41. When

- 15 -

the pressure, measured by pressure transducer 42 in cleaning chamber 10 reaches a sufficiently low threshold, door 60 of cleaning chamber 10 may be safely opened and the clean articles removed. In an embodiment of the present invention, 5 the CO₂ vapor may be released either to the system surroundings or outdoors via a venting pipe (not shown). Sound control muffler 46 and/or a throttling device (not shown) may also be utilized to control the venting rate.

10 While the embodiment of the invention shown and described herein is fully capable of achieving the results desired, it is to be understood that this embodiment has been shown and described for purposes of illustration only and not for purposes of limitation. Other variations in the form and details that occur to those skilled in the art and that are 15 within the spirit and scope of the invention are not specifically addressed. Therefore, the invention is limited only by the appended claims.

- 16 -

CLAIMS

1. A dry-cleaning process for cleaning articles disposed in a cleaning chamber using CO₂ from a storage tank, the cleaning chamber including a rotatable member, the process comprising:

causing a positive pressure differential between the storage tank and the cleaning chamber;

filling the cleaning chamber with a predetermined amount of liquid carbon dioxide (CO₂) by enabling flow of liquid CO₂ from the storage tank to the cleaning chamber in response to said positive pressure differential; and

rotating the rotatable member to agitate the liquid CO₂ in the cleaning chamber.

2. A process according to claim 1 wherein the step of causing a positive pressure differential between the storage tank and the cleaning chamber comprises compressing CO₂ gas into the storage tank using a compressor.

3. A process according to claim 1 further comprising the steps of:

causing a negative pressure differential between the storage tank and the cleaning chamber; and

draining the cleaning chamber by enabling flow of liquid CO₂ from the cleaning chamber to the storage tank in response to said negative pressure differential.

4. A process according to claim 3 wherein the step of causing a negative pressure differential between the storage tank and the cleaning chamber comprises compressing CO₂ gas into the cleaning chamber using a compressor.

5. A process according to claim 3 further comprising the steps of:

- 17 -

drawing CO₂ vapor from the cleaning chamber;
condensing the CO₂ vapor by compressing and cooling the
CO₂ vapor; and

returning the condensed CO₂ vapor to the storage tank.

5 6. A process according to claim 5 wherein cooling the
CO₂ vapor comprises passing the CO₂ vapor through a heat sink
which collects heat from the CO₂ vapor.

7. A process according to claim 3 further comprising
the steps of:

10 drawing CO₂ vapor from the cleaning chamber;
heating the CO₂ vapor; and
returning the heated CO₂ vapor to the cleaning chamber.

8. A process according to claim 7 wherein the step of
heating the CO₂ vapor comprises passing the CO₂ vapor through
15 a heat sink which transfers heat to the CO₂ vapor.

9. A process according to claim 6 further comprising
the steps of:

20 drawing CO₂ vapor from the cleaning chamber;
heating the CO₂ vapor; and
returning the heated CO₂ vapor to the cleaning chamber.

10. A process according to claim 9 wherein the step of
heating the CO₂ vapor comprises passing the CO₂ vapor through
said heat sink, whereby at least some of the heat collected
by the heat sink during the step of condensing the CO₂ vapor
25 is transferred back to the CO₂ vapor during the step of
heating the CO₂ vapor.

11. Dry-cleaning apparatus for cleaning articles
comprising:

30 a storage tank for storing carbon dioxide (CO₂);
a cleaning chamber having a rotatable member therein;

- 18 -

a rotation mechanism for rotating the rotatable member;
and

a compressor which creates a pressure differential
between the storage tank and the cleaning chamber sufficient
5 to transport liquid CO₂ between the storage tank and the
cleaning chamber.

12. Apparatus according to claim 11 further
comprising:

a heat sink in thermal communication with a CO₂ vapor
10 flow between said storage tank and said cleaning chamber and
operative to collect heat from relatively warm CO₂ vapor and
to transfer heat to relatively cold CO₂ vapor, whereby part
of the heat collected from the relatively warm CO₂ vapor is
transferred to the relatively cold CO₂ vapor.

15 13. Apparatus according to claim 11 wherein the
compressor is capable of raising the pressure in the storage
tank to at least 750 PSI.

14. Apparatus according to claim 13 wherein the
compressor is capable of raising the pressure in the storage
20 tank to about 900 PSI.

15. Apparatus according to claim 11 wherein the
compressor is capable of lowering the pressure in the
cleaning chamber to less than 150 PSI.

16. Apparatus according to claim 15 wherein the
25 compressor is capable of lowering the pressure in the
cleaning chamber to about 50 PSI.

17. Apparatus according to claim 11 wherein the
compressor comprises an oil-less compressor.

18. Apparatus according to claim 11 wherein the
30 rotation mechanism comprises a rotation drive and a coupling
between the rotation drive and the rotatable member.

- 19 -

19. Apparatus according to claim 18 wherein said coupling comprises a magnetic coupling.

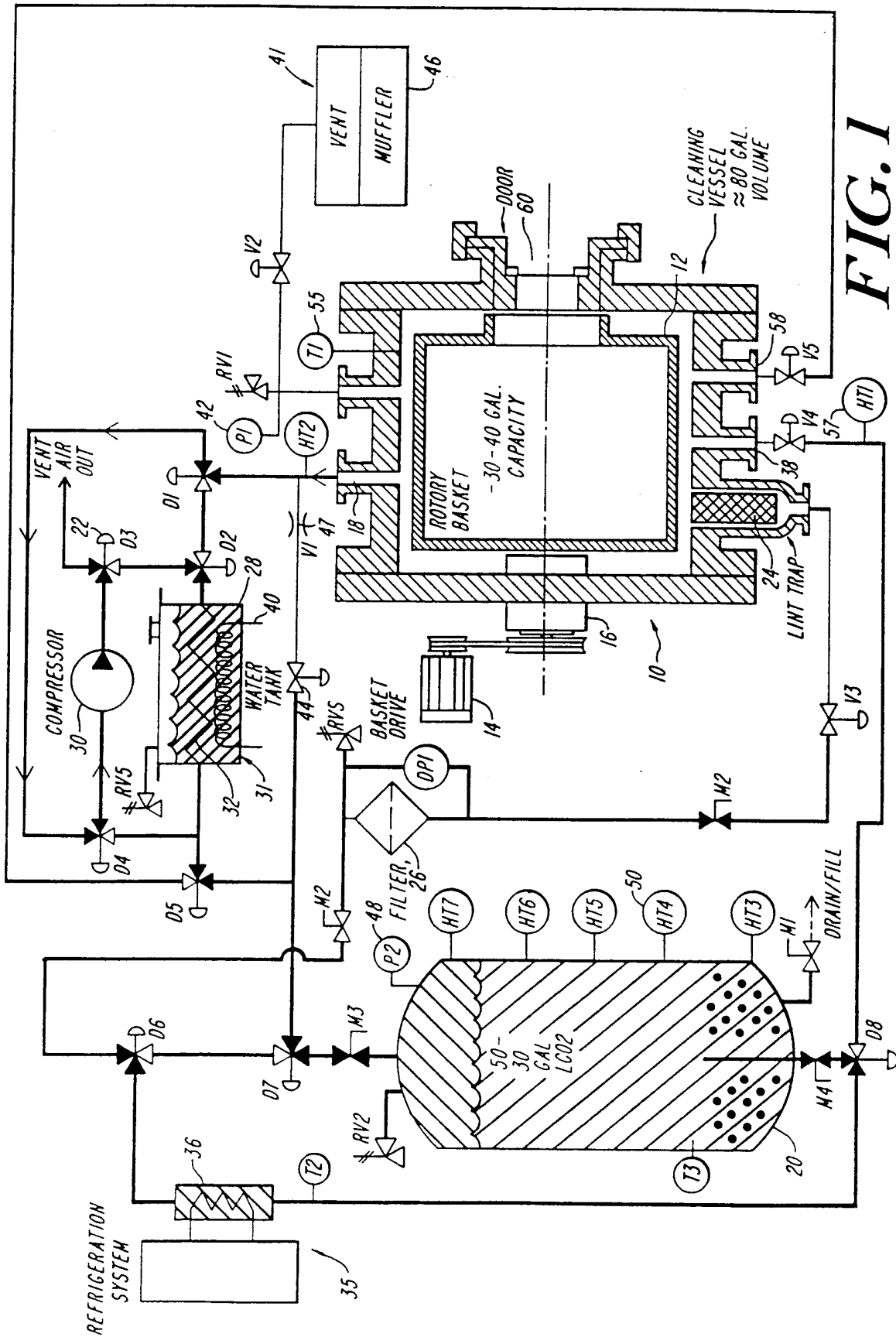


FIG. 1

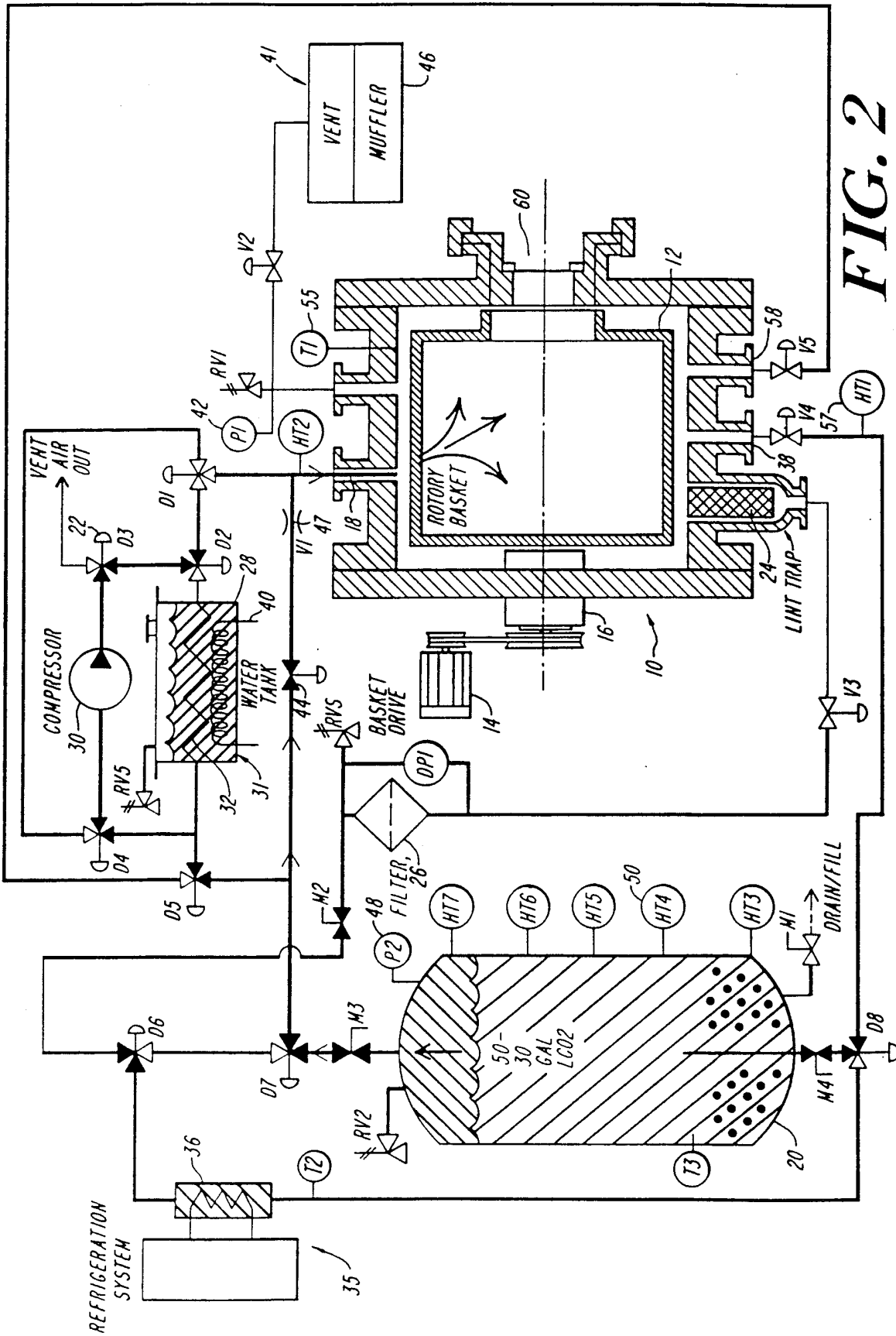


FIG. 2

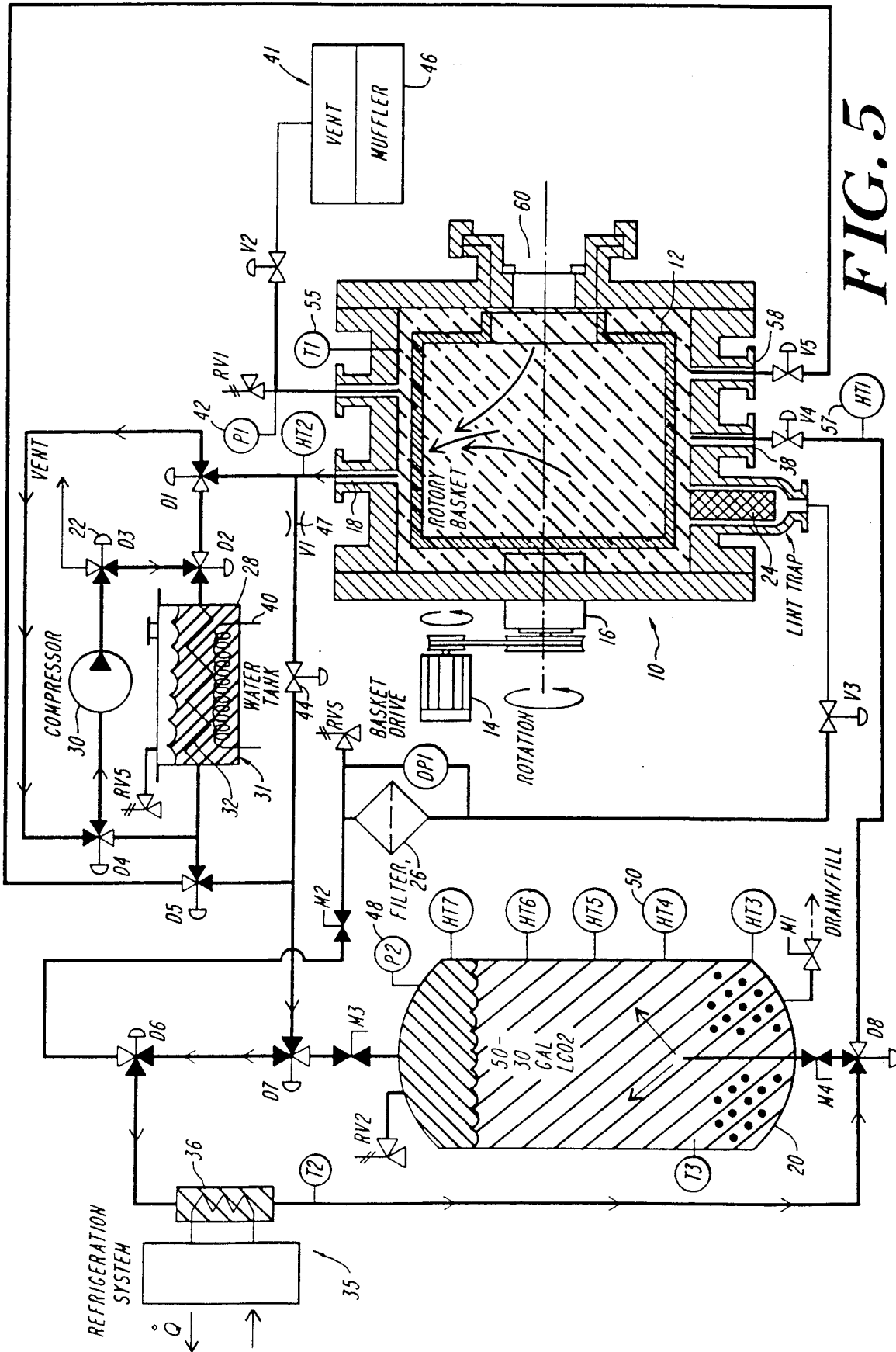


FIG. 5

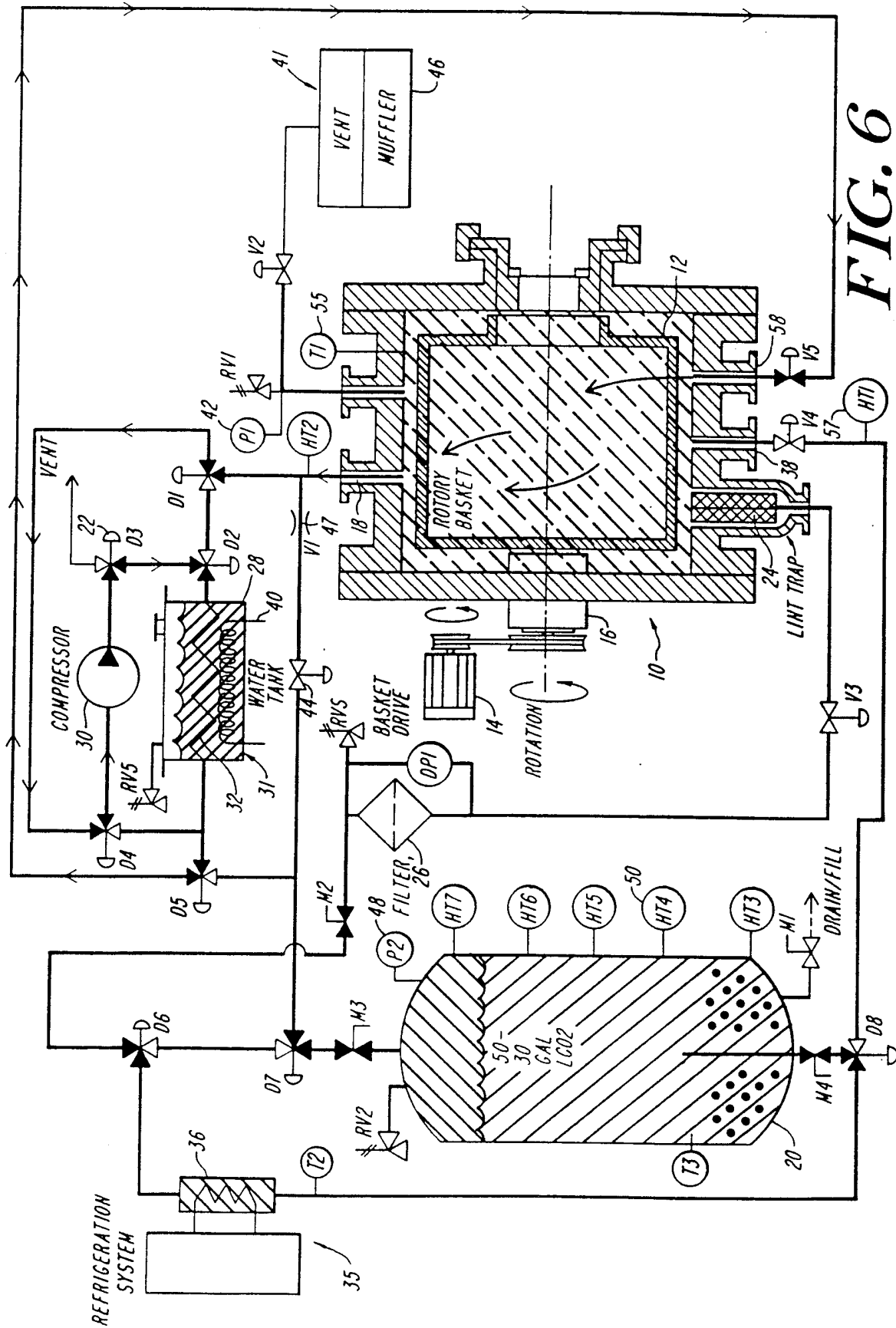


FIG. 6

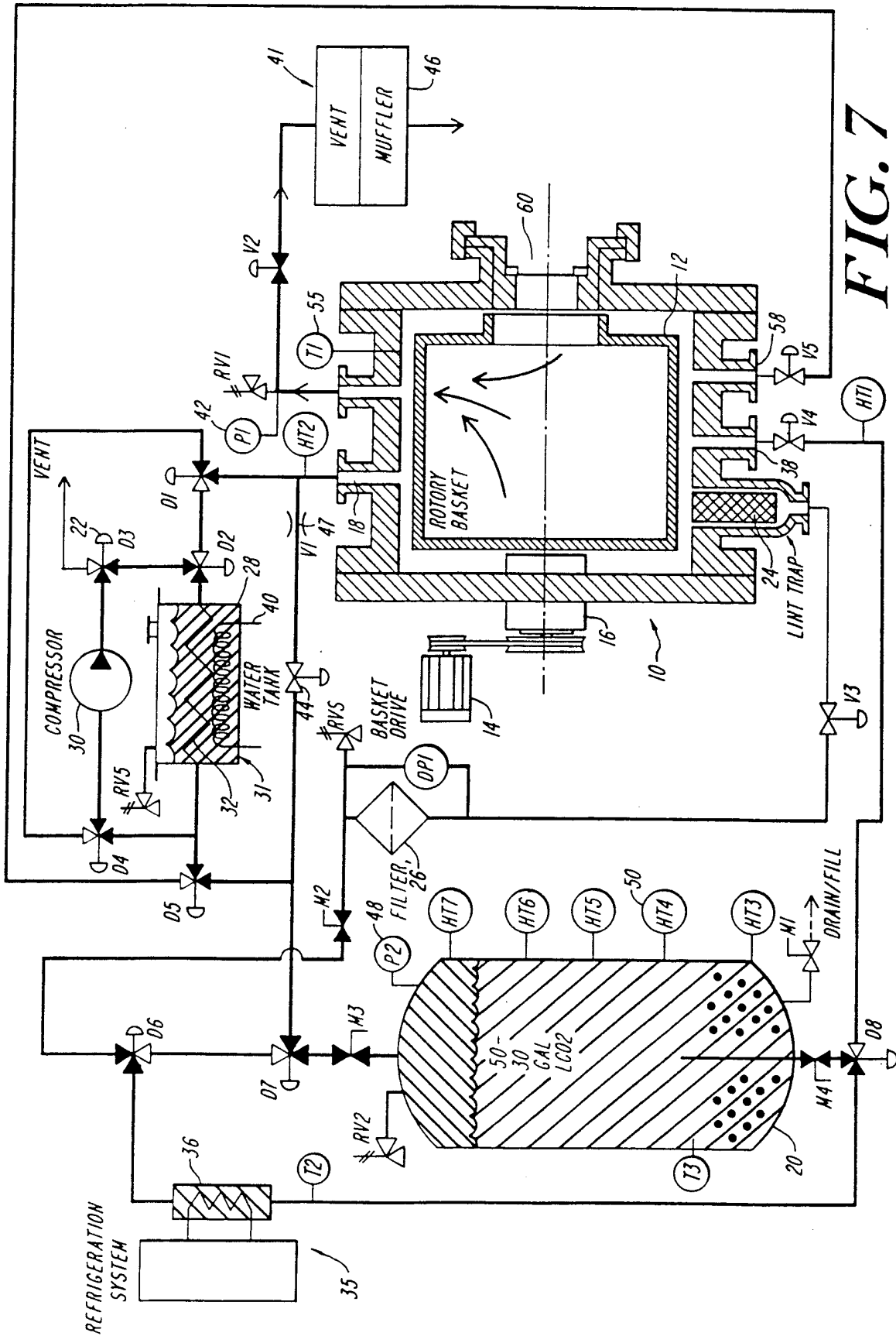


FIG. 7

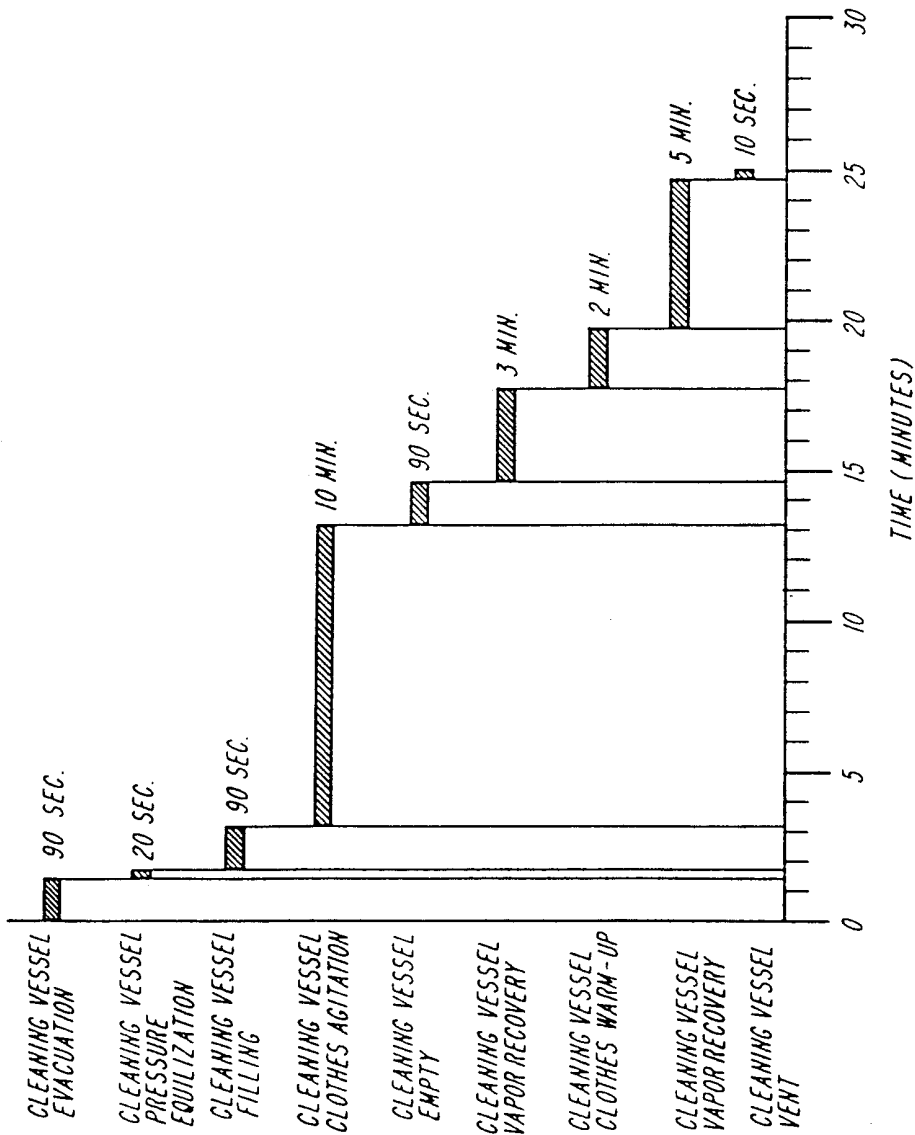


FIG. 8