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Utilization of Membranes for H_2O Recycle System

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ABSTRACT

Conceptual studies of closed ecological life support systems (CELSS) carried out at NAL in Japan for a water recycle system using membranes[1] are reviewed. The system will treat water from shower room, urine, impure condensation from gas recycle system, and so on. The H_2O recycle system is composed of pre-filter, ultrafiltration membrane, reverse osmosis membrane, and distillator. Some results are shown for a bullet train of toilet-flushing water recycle equipment with an ultrafiltration membrane module. The constant value of the permeation rate with a $4.7m^2$ of module is about 70 l/h after 500h of operation. Thermovaporization with porous polytetrafluorocarbon membrane is also proposed to replace the distillator.

WHEN A SPACE STATION is constructed as a permanent facility with long-term human habitation food, water and oxygen are indispensable. Operation cost must be kept as low as possible by reducing materials transported to and from the earth.

If the human wastes could be recovered and regenerated to produce food, water and oxygen a significant amount of mass transport from the earth could be reduced and the human wastes would not be returned back to the earth as on current manned flights.

On the earth, surface water is constantly evaporated by solar heat and recycled to the surface again as forms of raindrops and snow. In the space station, there is no such natural water recycle system available, so an artificial water recycle system is important and necessary for the purpose to establish a closed ecological life support system(CELSS).

2ND PHASE SPACE MISSION

The use of a CELSS in space habitats is the reason why a compact water recycle system is scheduled in the Japanese NAL study to test its performance under 0G condition in the second phase of a series of space missions. The system is composed of two main parts, a shower water recycle loop and a water purification loop. The shower water from the bath room, which is typically 20 liters per a shower, is fed into high pressure pump through a water filter, and then purified by a reverse osmosis (RO) membrane module. Purified water is stored in a tank and will be supplied for the successive use in a shower, and impurity such as residual condensation from the spacecraft atmosphere will be also sent to the water purification loop.

Table 1 summarizes the tentative operational specifications for the shower water recycling loop, and required measurement items for the system operation are indicated in Fig.1 and listed in Table 2.

The drainage from the shower water recycle system is introduced into the water purification system, together with other water drainage, urine and condensed expiration water. Accordingly, the system is required to have the capacity to handle the items in Table 3. The system will purify water by the integrated ultrafiltration membrane (UF), reverse osmosis membrane and distillator.

The entire system block diagram is shown in Fig.2 and the system design goal are tabulated in Table 4. In Table 5 monitoring parameters for the system operation are summarized.

To satisfy space station safety requirements, the system should be operated with an adequate interlock circuit. Particularly, the distillator should be designed with enough hazzard protections. Additionally, a vital area of research is determining the stability of membranes and filters over time, and monitoring the amount of residue in the recycled water.

The distillator is operated with a batch process mode, and contains a small centrifugal phase separator, heater, and air cooler for water condensation.

The residual impurity solution from the ultrafiltration module and distillator will be stored in a tank for a further processing by a waste management system.

The total system should be made compact to be contained in a small box so that it does not occupy a large space in space station. In Table 6, specification of the water recycle apparatus are listed. The schematic of the entire system is shown in Fig 3, and a three dimensional picture of the system is shown in Fig 4.

SOME RESULTS ON ULTRAFILTRATION MEMBRANE[2)]

For the purpose of obtaining reliable data for system design to treat waste water containing urine, feces and other solids, a brief summary of results obtained with an ultrafiltration membrane module is shown which is contained in toilet-flushing water recycle equipment specially designed for bullet train which is now on a development and demonstration stage. The ultrafiltration module has 4.7m^2 of surface are and is a hollow fiber type 0.8mm^O x 1.4mm^O x 1000mmL and made of polyacrylonitrile.

The toilet will serve 174 persons and will be used 26 times per hour. The total amount of volume of urine and feces per hour is estimated as 7 liters. The design specifications are listed in Table 7, and a flow diagram is shown is Fig 5.

Used water is pumped through a rotating strainer with 0.6mm slits and fed to a prefilter with 75 m screen and a rubber scraper. The filtered water is fed to ultrafiltration modules. Through which the permeation rate is about 200 l/h at the beginning but gradually decreared and reaches a stable value of 70 l/h after 500 hours of operation. The membrane life now obtaine is about one and a half years. The average values of the quality of permeate are listed on Table 8.

THERMOVAPORATION IN PLACE OF DISTILLATOR

Reliable data of the performance of reverse osmosis module will be obtained in the near future. Permeate through reverse osmosis membrane will be used as plant cultivation water after activated carbon treatment and UV-light sterilization.

Thermovaporization was proposed recently to replace the distillator for water for small animals. The membrane is composed of porous polytetrafluorocarbon. The pressure in the permeate side of the membrane is 50mmHg and temperature will be kept 20^{O}C. Membrane area needed is estimated as about 0.3m^2 to obtain distilled water at a rate of 5 l/6h.

LITERATURE CITED

1) "CELSS Experimental Concepts of Space Station Mission" CELSS Experimental Concept Study Group, Tokyo Japan April 16 ,1984

2) "Toilet Flushing Water Recycle Equipment Using High Flux Filtration for Bullet Tain" Association of Railroad Tain Industry Japan, March 1984

Table 1 Design Goal for Shower Water Recycle System

Item	Description
Water Recovery Ratio	>95%
Pressure Difference	<60 atm.
Capacity	>0.5 ton/day
Operating Time	≃5 Hr/day
Power	kW

Table 2 Monitoring Parameters for the Shower Water Recycle System

Location	Measurements
Pump Inlet	Temperature ,Pressure
RO Filter Inlet	Eletrical conductivity,Pressure
RO Filter Recirculation Loop	Flow rate
RO Filter Outlet	Electrical conductivity,Pressure

Table 3 Capacity Requirement for the System

Item	Amount
Urine	1.8 lit./man-day
Shower Drainage	1.0 lit./man-day
Expiration	1.2 lit./man-day
Other Drainage	1.0 lit./man-day
Total	5.0 lit./man-day

Table 4 System Design Goals

Item	Design Goals
Recovery Ratio(UF)	>90%
Pressure Difference(UF)	≃2 atm
Recovery Ration(RO)	>50%
Pressure Difference(RO)	<60 atm
Capacity	>5 lit./day
Operating Time	19 Hr/day

Table 5 Monitring Parameters for the Water Purification System

Location	Measurements
UF Filter Inlet	Electrical conductivity, Transparency,Pressure, Temperature,Urine content Biological oxygen demand (B.O.D.),Chemical oxygen demand(C.O.D.)
RO Filter Inlet	Electrical conductivity, Pressure,Temperature

Table 5 (continue)

RO Filter Recirculation Loop	Flow rate, Pressure
RO Filter Outlet	Electrical conductivity, Pressure
Distillator	Pressure, Temperature

Table 6 Specification of the Water Recycle System

Item	Specifications
Dimensions (mm)	450W x 1490H x 610D
Weight (kg)	about 330
Power (kW) Requirement	2.4
Membrane Filters	RO: 0.5 ton/day 0.5 m^2 Membrane area 20-40 atm Press. Diff. UF: 5 lit./day 0.5 m^2 Membrane area 2 atm Press.Diff.
Distillator	5 lit./Hr (Max.) Centrifugal Phase Separation

Table 7 Design Specifications for Toilet Flushing Water Recycle Equipment for Bullet Train

Item	Specifications
Tank for flushing Water	200 l (overflow)
Tank for used water	350 l (initial volume of water 150 l)
Ultrafiltration	70 l/h/module x 3 mod.
Prefilter	130 l/h/module x 2 mod.
Main pump	220 l/min, 22.5 m, 1.5kW
Flushing pump	27 l/min, 2 m, 0.4 kW
Maximum power	2.1 kW

Table 8 Quality of Permeate by UF

Item	Amount
BOD (mg/l)	257
COD (mg/l)	22.8
Suspended Solid (mg/l)	4.5
E.Coli	not detected
Oder (JIS K0102.10.2)	4.2
Transparency (JIS K0102.10.3)	16
pH	8.7
Color	white - yellow

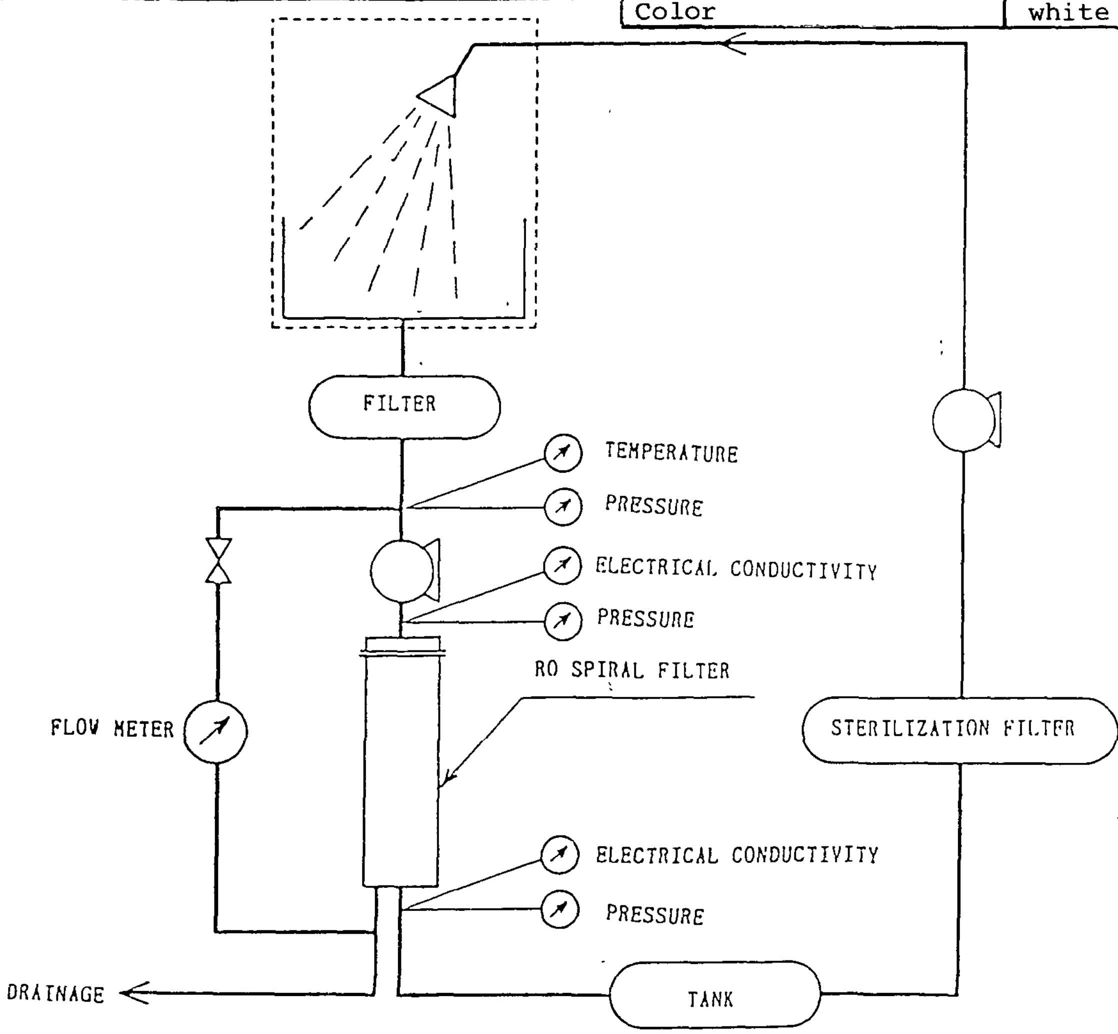

Fig. 1 Shower Water Recycle Loop

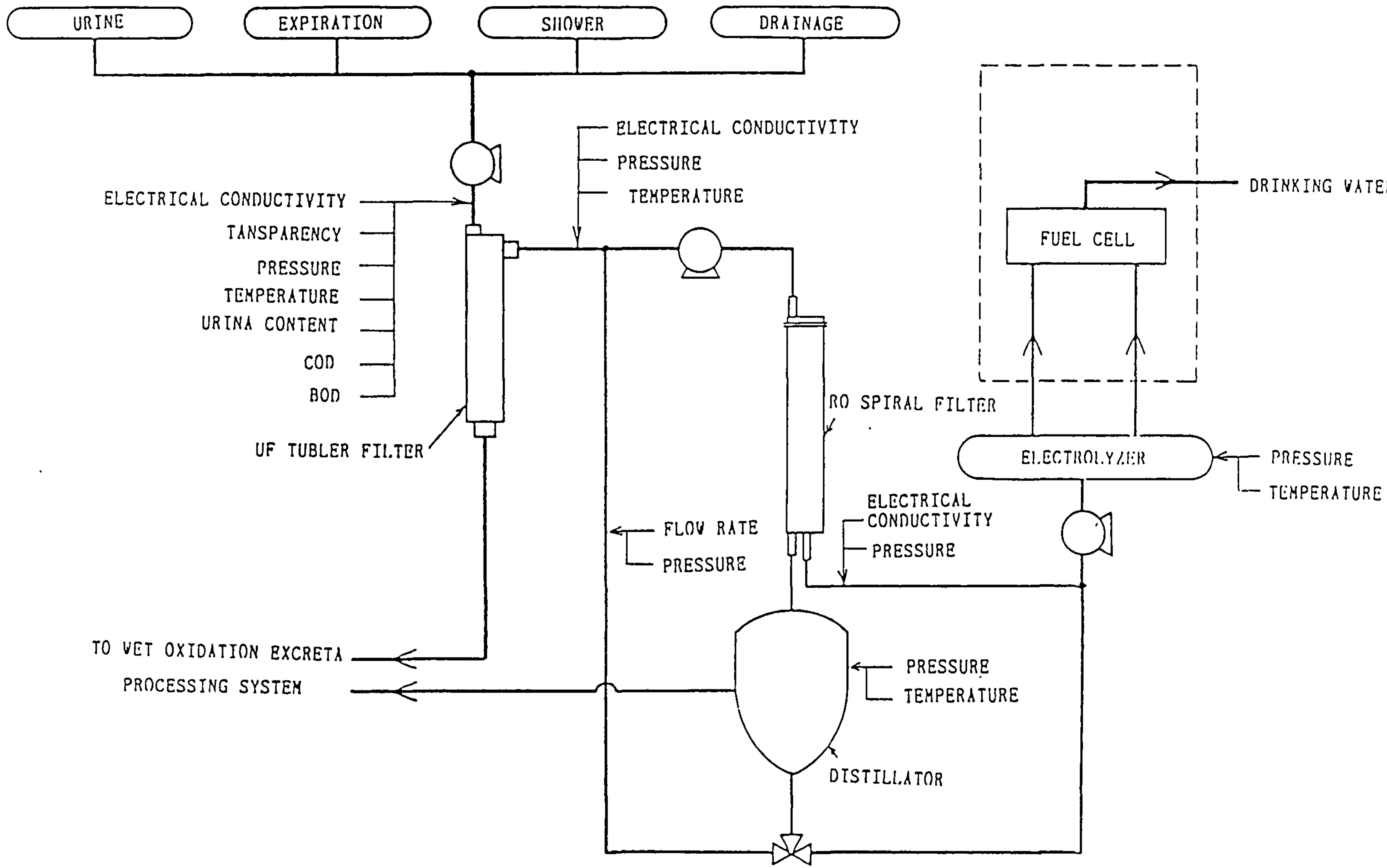

Fig. 2 Water Purification Loop

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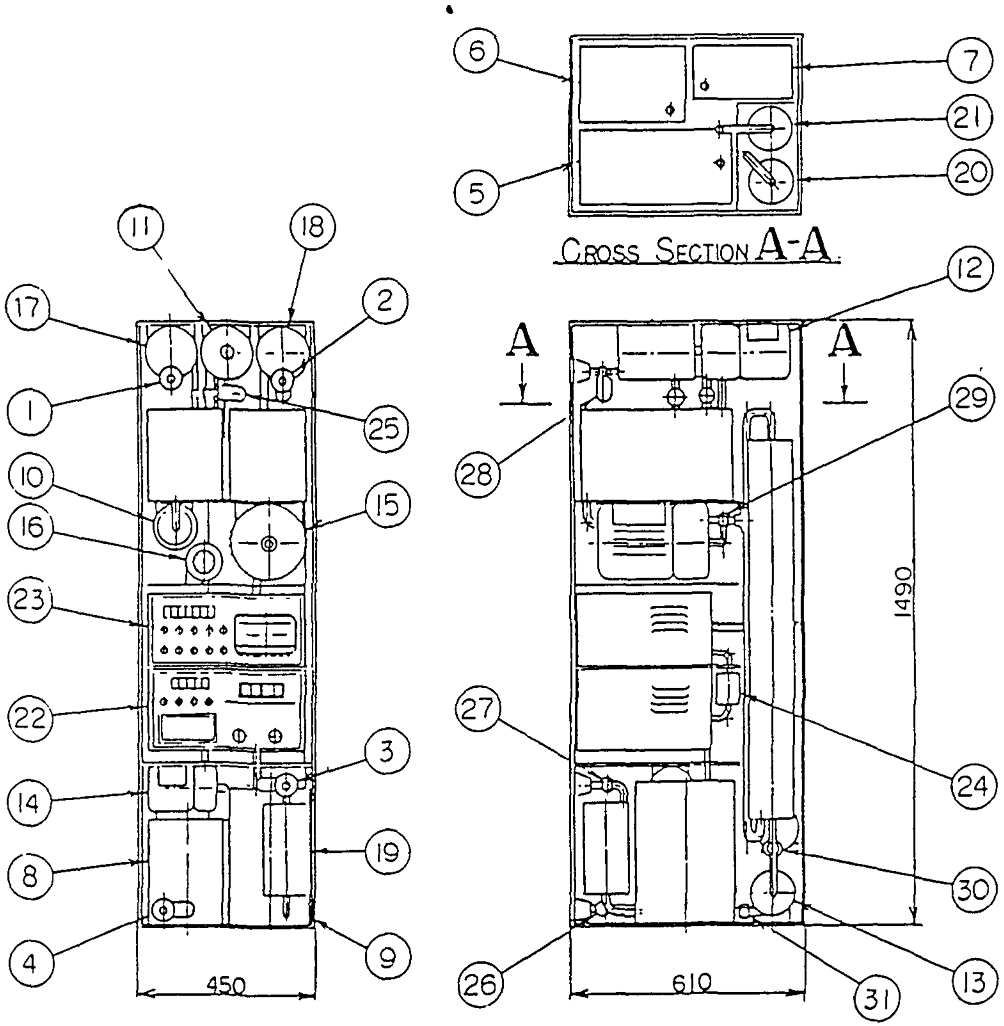

NO	TITLE
1	USED VATER/URINE INLET
2	SHOVER DRAINAGE INLET
3	SHOVER VATER OUTLET
4	RESIDUAL LIQUID OUTLET
5	TANK
6	TANK
7	TANK
8	TANK
9	TANK
10	PUMP
11	PUMP
12	PUMP
13	PUMP
14	PUMP
15	HIGH PRESSURE PUMP
16	BLOVER
17	FILTER
18	FILTER
19	STERILE FILTER
20	RO SPIRAL FILTER
21	UF TUBLER FILTER
22	DISTILLATOR
23	ELECTROLYZER
24	NaCl REMOVER
25	VALVE
26	VALVE
27	VALVE
28	VALVE
29	VALVE
30	VALVE
31	VALVE

Fig. 3 Composition of Water Recycle System

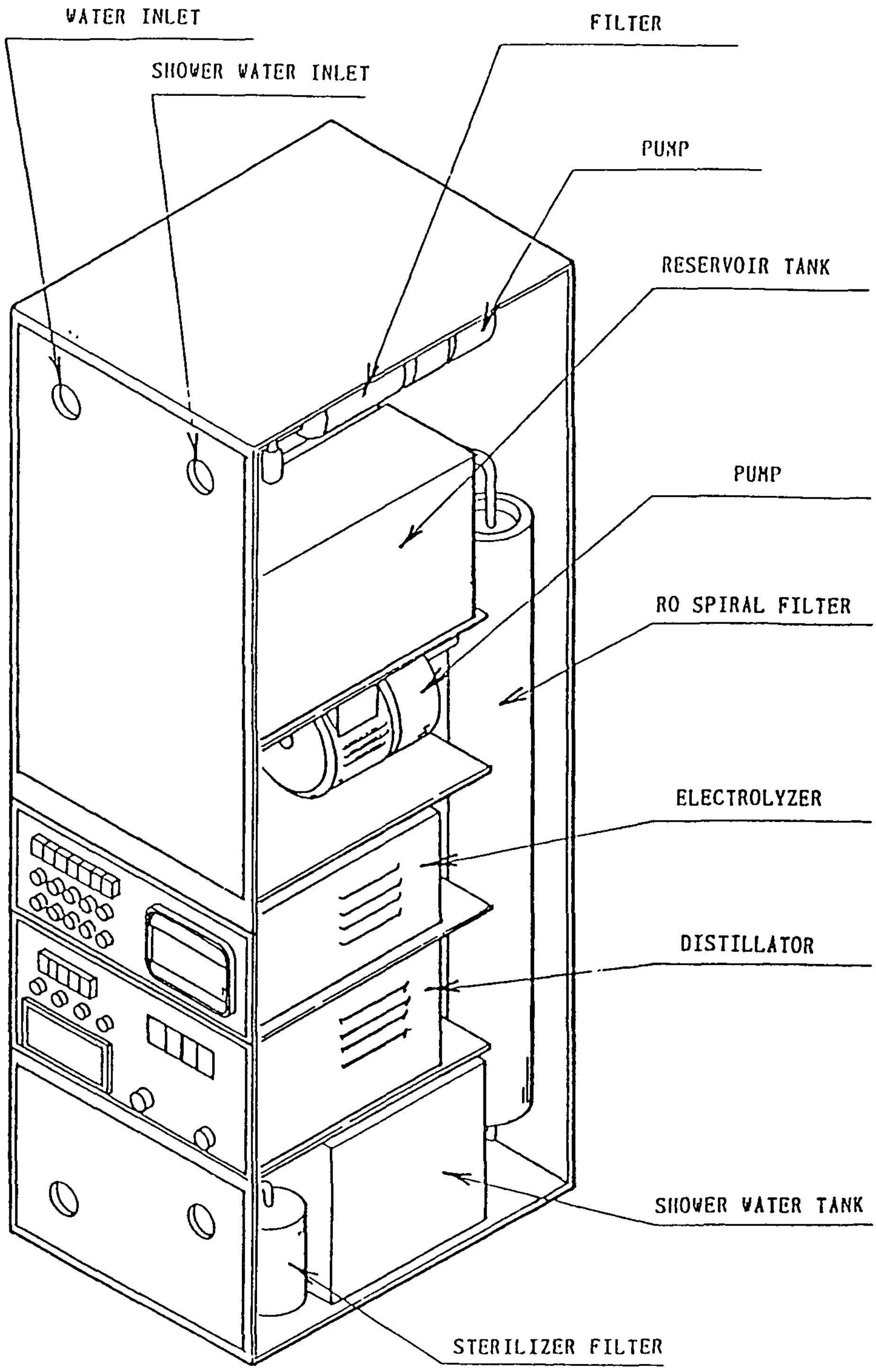

Fig. 4 Configuration of Water Recycle System

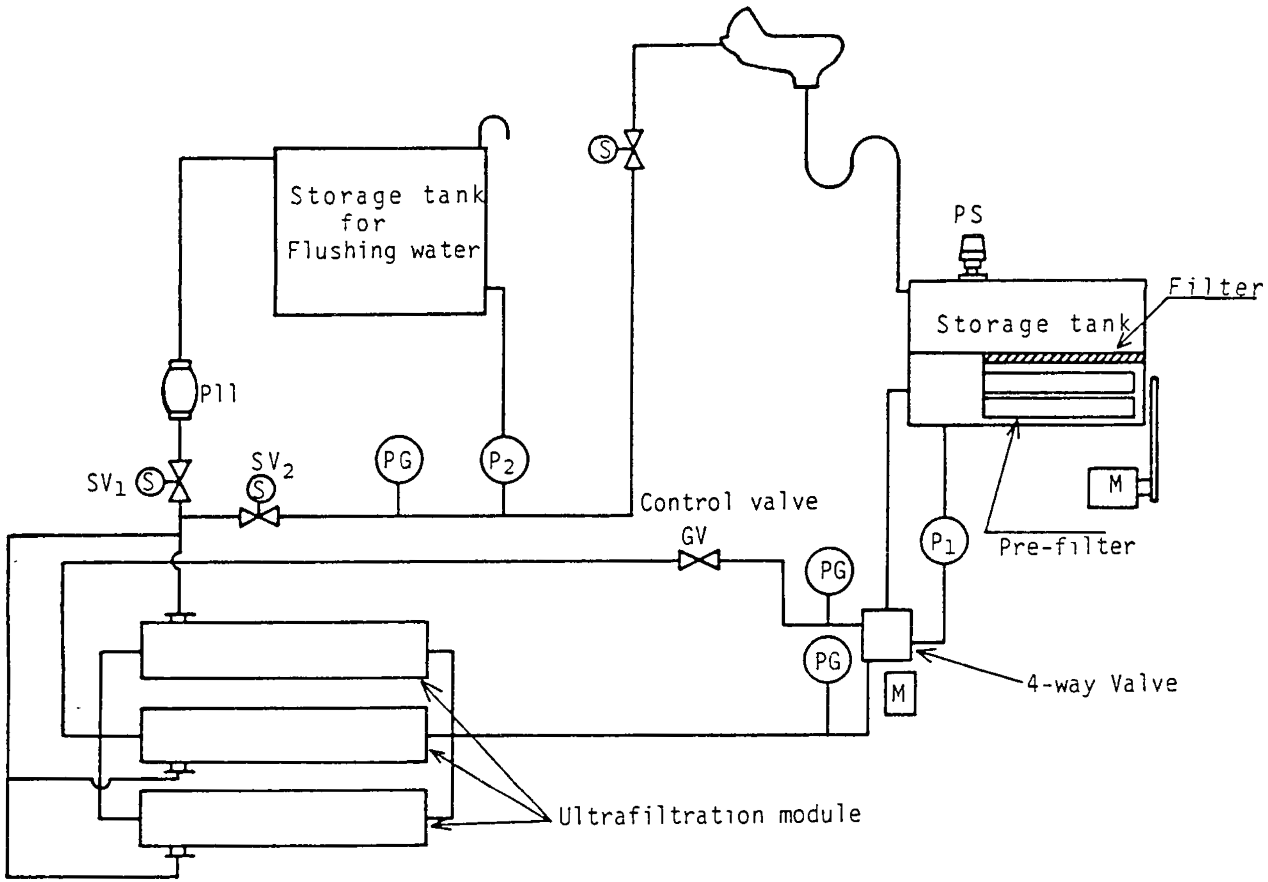

Fig.5 Flow diagram of toilet flushing water recicle equipment for bullet train