Recent Patents on Space Toilet

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Abstract: A space toilet is a toilet that can be used in a low gravity environment. In the absence of gravity the collection and retention of liquid and solid waste is directed by use of air flow instead of water. Generally, the human waste is separated and solid wastes are compressed and stored on-board, and then removed after landing. Waste water is vented to space. The air is filtered to remove odor and bacteria and then returned to the cabin. Since the air used to direct the waste is returned to the cabin, it is filtered beforehand to control odor and cleanse bacteria. In this article, some important patents related to space toilet or waste collection system will be reported and the corresponding approaches to collect, handle, and dispose space waste will be reviewed. The main advantages and drawbacks related to each technological approach will be pointed out, and future perspectives in the field will be discussed.

Keywords: Space toilet, collection, handling, disposal, zero gravity, waste.

INTRODUCTION

Once in orbit, the spacecraft and everything inside it experience a condition called microgravity. Since there is no gravity to either hold a toilet bowl full of water in place or pull human wastes down, in the closed and limited volume of current spacecraft, waste collection, handling, and disposal, further complicated by absence of significant quantities of power and water, is not an easy task.

A space toilet, or zero gravity waste collection system, is a toilet that can be used in a low gravity environment. In the absence of gravity the collection and retention of liquid and solid waste is directed by use of air flow. Since the air used to direct the waste is returned to the cabin, it is filtered beforehand to control odor and cleanse bacteria. In older systems, waste water is vented into space and any solids are compressed and stored for removal upon landing. More modern systems expose solid waste to vacuum to kill bacteria, which prevents odor problems and kills pathogens.

The first in flight solid waste collection system was an adhesive rimmed bag stuck on the subject's buttocks with a finger cot molded in for removal of adherent material. Skylab used a seat with an individual, replaceable bag collector, integral filter, and flow through air entrapment system. Individual bags were then vacuum dried and stored for return to earth. Because of the size, complexity and power cost of the Skylab waste collection system, a more efficient system was designed for the space shuttle. This system used a single large pot with a centrifugal macerator/slinger which would plaster the pot walls with successive layers of fecal material, which were subsequently dried by vacuum. There are serious operational difficulties with this system.

A number of patents disclose an array of waste collection devices, many of which are designed for space flight. These patents disclose vacuum and air assist means, bagging means, and sweep means (in the form of bare pistons). An example of a zero gravity toilet with a buttocks-conforming seat is found in [1]. The seat creates an airtight seal against the subject's buttocks. High pressure fluid is directed through jet means to the subject's anus, thereby washing it clean following use. Positive pressure in the water collection system cavity forces the water down a tube sending it into a low pressure collection receiver. The fluid contains reagents which will form a resin plug in, the depending tube. The plug, urged by air pressure, will be forced down the tube and clean the passage as it advances.

[2] discloses a space toilet which includes a vacuum suction means combined with air flow jets located around the periphery of the seat. The vacuum means is used to draw the liquid and solid waste material into a gas permeable collection bag. A second bag encompassing the first is completely impermeable. The first bag is manually sealed by the user within the second bag, and dropped into a continuously heated dessication chamber which is sealed by a piston. The piston is not used to compress, but merely to seal the dessication chamber from the waste collection area, and prevent the escape of odor.

A flush toilet which utilizes positive control over a liquid flushing medium is' described in [3]. A current of air supplied near the seal between the seat and the subject's buttocks, directs both feces and odor to the toilet bowl outlet. A water jet is provided to cleanse the rectal area which is followed by a drying jet of warm air. Water under pressure is used to wash the toilet bowl, and the liquids and feces removed through the bowl outlet conveyed to a blender. Urine and the feces/water mixture from the mechanical blender are pumped to a vacuum distillation unit. Distilled water from the vacuum distillation unit is then available for future flushing. A continuous low pressure is maintained in the system, preventing the escape of odor into the cabin.

Some of waste collection devices are not designed for space flight, but can be used in space flight. An example of them can be found in [4]. When an elderly person is confined

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to bed, or a patient is suffering from a spinal cord injury, and has the automatic urine collecting apparatus of this invention fastened to him, has urine incontinence, the sensor of the system detects the first drop of discharged urine. The urine is automatically carried along with the air sucked from the urine receiving unit and transmitted to a urinal. The air is supplied to the urine receiving unit through a multitude of small holes bored at the top thereof and a soft vinyl tube connected thereto and extended outside. To further supply air into the urine receiving unit, a vinyl tube may be connected to a pipe discharging the exhaust air during the time a pump is operating. The urine so collected is disposed of by customary means.

In this article, a patented waste collection device described in [5] will be reviewed, which can efficiently solve the problems encountered in space flight. The waste collection device is compact, efficient, and combines air flow means, piston means, replaceable facing pads, and a storage means.

The Waste collection system can be viewed for clarity and simplicity as a number of sub-systems interrelated structurally and functionally to provide an efficient means of collection and storage of fecal matter. The sub-systems consist of the following: a ventilation means to prevent odor from emanating from waste collection system and for driving, by use of air currents, fecal matter, wipes and cleaning material of the user into waste collection area; a sweep and compaction means, either manual or motor driven, that removes fecal matter, wipes and cleaning material from waste collection area; a waste storage area for retaining collected fecal matter, wipes, and cleaning material; a sheet replenishing means working in conjunction with the sweep means and waste storage area and designed to keep the sweep means and waste collection area free and unsoiled by fecal matter; and a valve system designed to control removal of air from body during the operation of the sweep means.

Figure (**1**) shows the main components and sub-systems of waste collection system. Body encloses therein waste storage area, waste collection area, and piston storage area. Body rests on frame. Seat is mounted on body over waste collection area and is preferably constructed of molded, resilient material that will conform to the human buttocks. Seat encircles seat opening which allows communication between user and waste collection area. Thigh restraints are required for weightless environments.

THE COLLCCTION APPROACH

Prior to defecation, user must: (1) retract piston from its "stored" position; (2) activate sheet feed mechanism; and (3) turn on blower motor.

When piston scissors place piston in a retracted position as shown in Fig. (**4**), the sheet feed mechanism will "grab" sheets from sheet roll and pull them up across piston, then cut off sheet. In this manner, piston face will have a clean sheet, prior to commencement of each "flush" operation.

When blower motor is on ventilation fan will create a negative pressure within body. Air, drawn in through body, thereby sweeps fecal matter into waste collection area. Since piston is retracted as illustrated in Fig. (**1**), occlusion valve, with its numerous plate orifices, is open into waste collection area, to allow the flow of air therethrough and thus out of body.

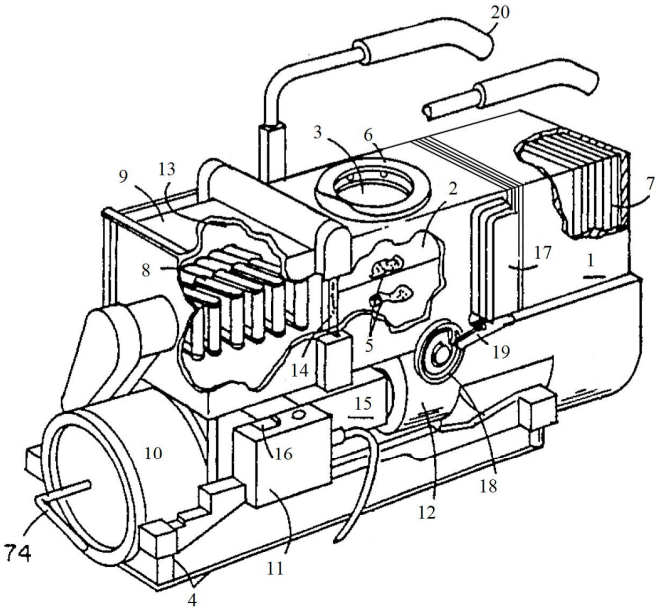

Fig. (1). Shows the main components and sub-systems of waste collection system. 1 - waste storage area, 2 - waste collection area, 3 - seat opening, 4 - frame, 5 - fecal matter, 6 - seat, 7 - soiled sheets, 8 - piston scissors, 9 - piston storage area, 10 - odor filter, 11 - motor, 12 - blower motor, 13 - piston, 14 - sheet, 15 - sheet feed mechanism, 16 - ventilation fan switch, 17 - occlusion valve, 18 - cam, 19 - rocker arm, 20 - thigh restraints.

Occlusion valve pivotally attached rocker arm engaged at one end to cam. Cam is in turn driven by a gear box and axle shaft arrangement at end of cam drive shaft. Rotation of crank rotates cam drive shaft through crank chain. Therefore, the rotation of crank can also open occlusion valve, allowing air to flow therethrough.

During defecation, fecal matter, wipes and cleaning material are deposited in waste collection area. Blower motor is actuated by ventilation fan switch. Blower motor, turned on prior defecation, creates a lower pressure within body than without. As a result of this pressure differential, air is drawn in through jets or slots at the base of seat and between any spaces between the buttocks of user and seat. Nozzles may be manually adjusted to control not only the amount of air passing therethrough but also the direction of the air. During use of waste collection system, most of the air is drawn in through jets when there is a good seal between the user and seat. However, all or some of the air coming through jets can come through slots along seat perimeter. Jets may be adjusted to change direction of air flow therefrom. Nozzle may be rotated and thus control the amount of air flowing therethrough, in the same fashion as the nozzle of a garden hose may be rotated to adjust the flow of water therethrough. An air pump may be adapted and connected to jets so that user may manually switch air pumps on to increase the flow of air through jets beyond the flow created by the low pressure within body. That is, there is an overdrive that will send compressed air through jets by manual operation of an air pump. The purpose for this is to

allow more efficient separation of the bolus from the rectal area of the user.

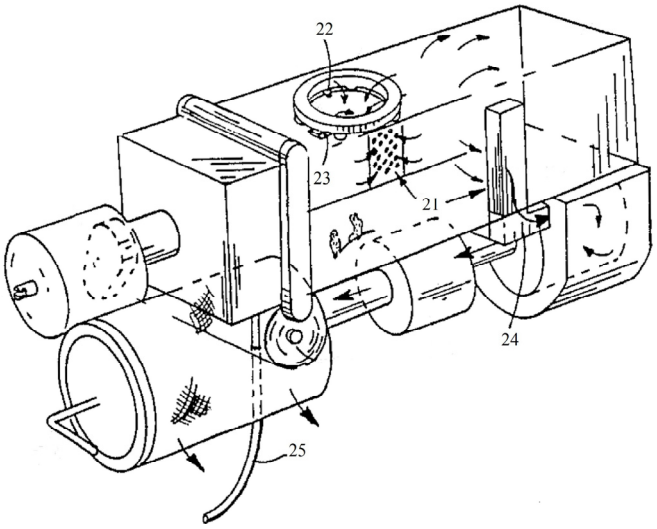

Fig. (2). The air flow through waste collection system. 21 - plate orifices, 22 - Jets, 23 - Nozzles, 24 - channel, 25 - tap.

In space, since there is no gravity to pull down the waste in human's recta, it is difficult for an astronaut to get rid of constipation. The application of an air pump not only can improve the efficiency of waste collection, but also can help an astronaut to eliminate the trouble caused by constipation to some extent. In order draw waste out of astronaut's recta, the attraction generated by air flowing has to be big enough. However, superfluity of attraction may cause some harm to the astronaut. That is to say, the amount of air flow through jets in unit time has to achieve some threshold with slight overmuch. Furthermore, the threshold has great deal to do with the ropy degree of waste. By means of rotating nozzles to control the amount of air flowing, and/or manually switching air pumps on/off to increase/decrease the flow of air through jets, more proper attraction can be obtained and the process of an astronaut's defecation will become smoother and more secure. It is an important progress in technology to introduce adjustable-flux nozzle and manually switch air pumps into waste collection approach, to say the least of it.

THE HANDLING APPROACH

After a user has made deposits of feces, wipes and cleaning material in waste collection area, he rotates crank (see Fig. **3**) which actuates piston scissors. Piston scissors are attached to piston and can extend and retract piston across waste collection area. Functionally, scissors are piston actuators. Under the action of piston scissors, piston moves through waste collection area (Fig. **5**), collecting fecal matter, wipes and cleaning material ahead of sheet. This action continues until the previously compacted feces stored between soiled sheets is encountered. At this point controlled pressure is applied causing fecal matter to spread radially and bonding waste material between previous soiled sheets and current sheets. On retraction of piston, fecal matter adheres to the previously compacted mass of soiled sheets and sheet facing piston, removing sheet from piston. Sheet has an impervious layer adjacent piston to prevent soiling by seepage. In this manner, fecal matter is swept from waste collection area, compacted and stored in waste storage area under compression by force of piston until next use. This results in minimal possible storage volume.

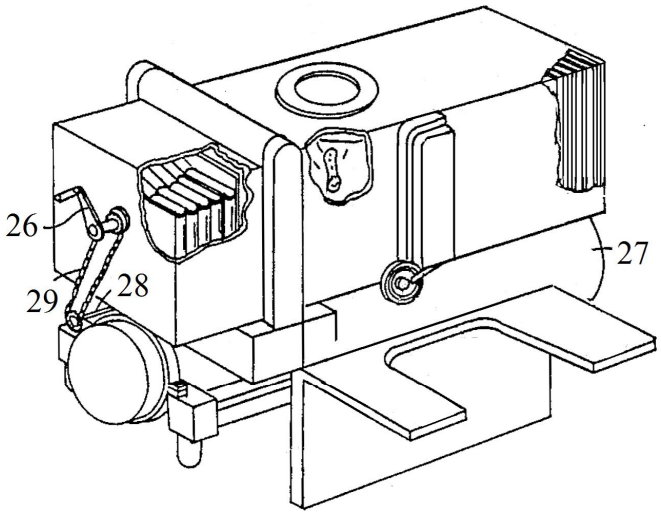

Fig. (3). A different embodiment of waste collection system. 26 - crank, 27 - hydrophobic filter, 28 - cam drive shaft, 29 - crank chai.

As piston retracts metal, rubber or other flexible material is utilized as a flap valve mechanism on the rear of piston face to open and relieve negative pressure created when piston is retracted. That is, without this pressure relief flap, when piston is drawn it will pull soiled sheets back under the negative pressure created by piston withdrawal. When piston is retracted to a position past sheet feed mechanism, the user is ready to replenish piston face with new sheet and waste collection system will be ready to use again. In this manner waste collection system repeats cycles of collection and compression, thereby storing fecal matter, wipes and cleaning material deposited in waste collection area.

As shown in Fig. (**1**), piston scissors are composed of many pairs of scissors with the same shape, and are assembled end to end. Let us first analyze the shape transformation of a pair of scissors. In Fig. (**4**), A and B stand for two end points of a pair of scissors, "O" stands for the axis center of a pair of scissors, $x(t)$ stand for the distance between A and B at time t, a stand for the distance between O and B, $h(t)$ stand for the high of ΔOAB at time t, then we have

$$h(t)^2 + \frac{x(t)^2}{4} = a^2$$

Deriving the last equality with respect to t gives the following expression

$$h'(t) = -\frac{x(t)}{4h(t)}x'(t)$$

Note that absolute value of $\frac{x(t)}{h(t)}$ tends to be zero monotonously when x tends to be zero. That is, if dx, expressing the approaching rate between A and B, is a constant, then $h'(t)$ will minish gradually when $x(t)$ tends to be zero. On the other hand, in order to compact

waste in waste storage area and result in minimal possible storage volume, the force acted on piston, denoted by $F(t)$, has to increase gradually. In this way, we can choose function $x(t)$ properly such that the product $F(t)\cdot h'(t)$ to be some constant such as c. In fact,

$$F(t)\frac{x(t)}{4h(t)}x'(t)=-c$$

$$x(t)x'(t)=-\frac{4ch(t)}{F(t)}$$

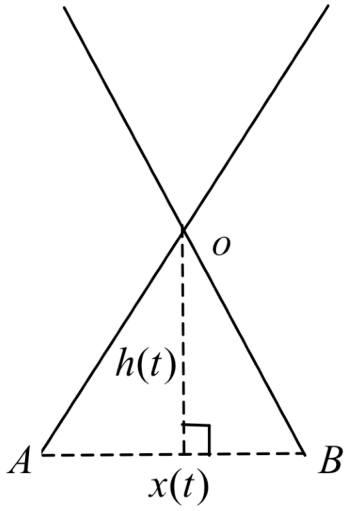

Fig. (4). The shape transformation of a pairs of scissors.

Integrating the two end of the last equation we have

$$x(t)^2=x(0)^2-8c\int_0^t\frac{h(t)}{F(t)}$$

So

$$x(t)=\sqrt{x(0)^2-8c\int_0^t\frac{h(t)}{F(t)}}$$

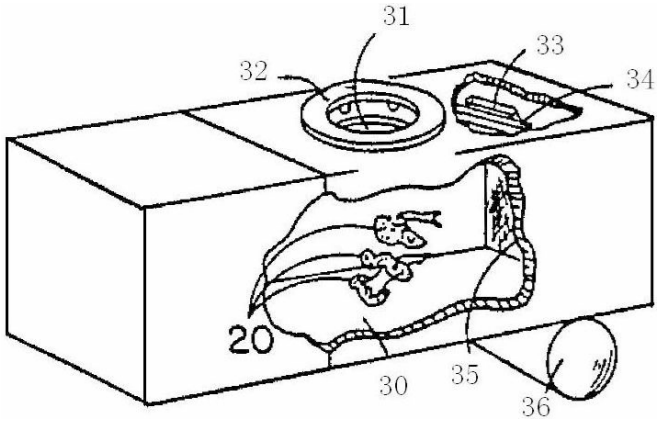

Fig. (5). The "armed" position of waste collection system. 30 - waste collection area, 31 - seat opening, 32 – seat, 33 - piston scissors, 34 - piston, 35 - sheet, 36 - sheet roll.

Since $F(t)\cdot h'(t)$ is the power required for driving piston, its constant value is helpful to choose piston actuator and make it easy for an astronaut to rotate crank, as long as the driving machine of piston is best designed such that the distance $x(t)$ between A and B satisfies the last equality. But the above advantage will vanish after replacing the piston scissors by a telescopic link, since a telescopic link can only drive piston to go forward with a uniform speed.

THE DISPOSAL APPROACH

During defecation, the air moves out of body through occlusion valve and into hydrophobic filter. Occlusion valve prevent solid material such as fecal matter from passing therethrough by utilizing a multiplicity of small plate orifices. Air is drawn from occlusion valve through channel into hydrophobic filter. Liquid and all particles, including bacteria are removed from the air by hydrophobic filter, leaving only dry air. This dry air is drawn through blower motor and directed into odor filter. Odor filter, made of activated charcoal or other suitable material, removes disagreeable odors from the air. Dry, odorless, bacteria and particle free air is then expelled into spacecraft through sides of odor filter.

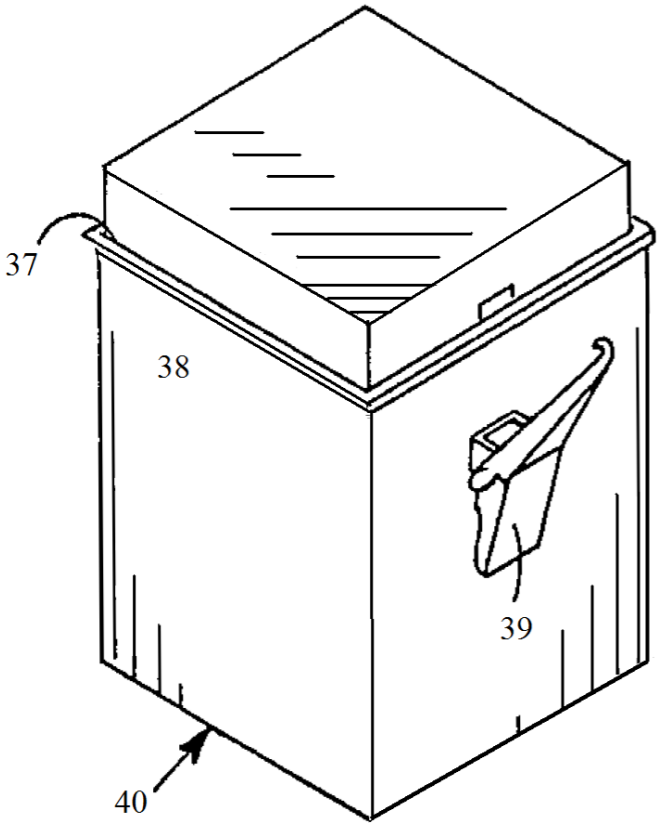

Fig. (6). The waste collection area without any type of removable insert.

Vacuum tap (Fig. **2**) is an air bleed line connected with the outside of the spacecraft (or some other source of negative pressure), thereby creating a slight negative pressure within body even when blower motor is not on. Such a slight negative pressure allows the continual, slight air flow into and through waste collection system and out vacuum tap. This removes gases and disagreeable odors from waste collection system when blower motor is not in operation.

The waste storage area is removable from rest of body (Figs. **6**, **7**). The inside of waste collection area is lined with a flexible bag insert (much like a garbage can liner) as illustrated in Fig. (**7**) or rigid container shaped to conform to the interior dimensions of waste collection area as illustrated in Fig. (**7**). The removable inserts bag or rigid container allow the occupants of the spacecraft to periodically remove accumulated soiled sheets from waste collection area. Bag insert can be tied by tie upon removal to prevent odor from escaping. User would then re-line interior of waste collection area with fresh insert bag. Rigid container insert may be sealed with an appropriate lid, in a manner much like Tupperware containers are used to store leftovers. Latch mechanism is designed to pull flange close against body. Gasket on flange made of an appropriate flexible material such as rubber, would insure a good seal against body.

In the waste collection device, liquid and all particles, including bacteria are removed by a hydrophobic filter, disagreeable odors are removed by an odor filter, and then dry, odorless, bacteria and particle free air is expelled into spacecraft for reuse. The approach to disposal air is very efficient and satisfactory. Nevertheless, it's a pity that the waste water can not be decontaminated for reuse.

It is said that the cost of launching payloads into low-earth orbit from Earth's surface is around $6,000−10,000 per kilogram. Obviously, it's expensive to take or ferry water from Earth. That's why NASA is following several different but complementary avenues at four agency centers to develop dependable ways of recycling water. Especially on long missions, water must be recycled and reused as much as possible [6].

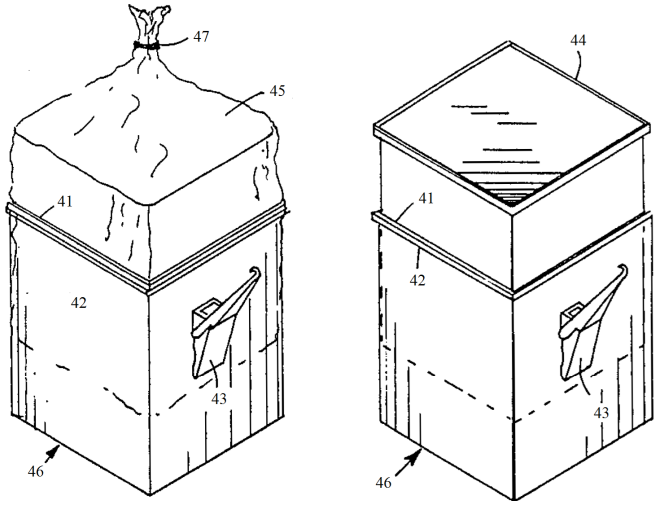

Fig. (7). The waste storage area removable from rest of body. 41 - Gasket, 42 - flange, 43 - Latch mechanism, 44 - rigid container, 45 - bag, 46 - waste storage area, 47 – tie.

FUTURE PERSPECTIVES

Dejection can not be reused, at least so far. However, the water contained in dejection can be reused someways, e.g., by centrifugal drying followed by electrical drying. After centrifugal drying, the great part of water contained in dejection can been collected. Heating the resulting dejection we first obtain steam, and then water will be obtained by cooling of steam.

It is very difficult for dejection to be recycled and reused in space. So far, there has not been any correlative technology to be patented. In older systems, dejection is compressed and stored for removal upon landing. In More modern systems dejection is exposed to vacuum to kill bacteria or discard into space after pulverization. A boldness idea is conversion of dejection to energy.

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