AEROSPACE GAS/LIQUID SEPARATOR FOR TERRESTRIAL APPLICATIONS

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ABSTRACT

The space gas/liquid separator, a key component in the heat transport subsystem of a space reactor power system, was developed to remove helium gas from liquid lithium in zero gravity. Helium is generated from lithium irradiation in the reactor core and would reach saturation in lithium after 48 hours of full power operations. In zero gravity space, the helium bubbles would nucleate on the coolant containment walls, grow and be swept into the lithium flow. The helium bubbles in the flowing lithium will reduce heat transfer to and from the coolant, increase pressure. drop in the. coolant and reduce the system's power generation capacity. The helium bubbles could also attach to the fuel pin walls within the reactor core, possibly blanket some section of fuel pins, increase fuel pin temperatures and decrease operating system lifetime, A gas/liquid separator was developed that consists of a containment vessel, a swirler, a filter screen and a storage screen. 'I'he swirler induces centrifugal force. which causes the lower density gas to accumulate over the center axis, All coolant flow passes through a filter screen, The screen pores size is designed so that surface tension in the pores will remove 100% of the helium bubbles that are 200 micron or larger from the lithium flow.

The following terrestrial applications are a direct result of a new technology that was developed for a space power system. One applications is removing air from coke. syrup just prior to mixing with carbonated water. Another application is removing air from purified water prior to carbonating the water. The gas/liquid separator is also applicable for large commercial powerplants to deaerate the water before and after the feedwater heaters. Another terrestrial application is for industrial Companies to use the gas/liquid separator and wet chemist, to remove all the, gasses from the. air and only discharge clean air to the atmosphere. An additional application that resulted from this gas/liquid separator technology, was separating liquid carbon dioxide from nitrogen. This application is opposite from the space application in that it is removing a liquid from a gas rather than a gas from a liquid.

AEROSPACE GAS/LIQUID SEPARATOR

The Space Reactor Power System, know as SP-1OO, has a heat transport subsystem that includes a gas separator/accumulator, a thermoelectric electromagnetic pump, a thaw accumulators, auxiliary cooling and thaw components and the lithium containment piping. The heat transport subsystem of the power system is shown in Figure 1. The gas separator technology developed, Choe, H. et al. (1 989), is summarized in this paper.

Functional Description

The SP-1 OO gas separator/accumulator discussed by Buksa (1994), a key component in the heat transport (HT) subsystem, separates and accumulates gases from the. lithium coolant. It also accommodates thermal expansions of the lithium coolant over the range of operating temperatures from cold start-up to full power. The separator maintains the system pressure. during operation.

The primary function of the gas separator/accunlulator is to separate and collect helium gas from the lithium coolant, Helium, tritium, deuterium and hydrogen arc all produced from neutron interactions with lithium. The bulk of this production occurs within the reactor core, Fortunately, hydrogen, deuterium and tritium all have relatively high diffusivities through niobium-based alloys of which the HT coolant boundary is comprised. Thus, these three gases readily leak out into space. The helium produced remains within the HT coolant boundary, as helium has a low diffusivity through niobium-based alloys.

If the gas separator was not present, the helium would reach saturation within the lithium coolant within 48 hours after the start of full power operations. Bubbles would begin to nucleate on the walls of the HT loop and as the helium bubbles grow, they will be swept into the flow field. The presence of these bubbles in the flowing lithium will reduce the effective electrical conductivity of the coolant and increase the hydraulic resistance in the pump, which will reduce the system's power generation capacity. The bubbles also may become trapped within the core or possibly even blanket the core, at low power. This would increase fuel pin temperatures.

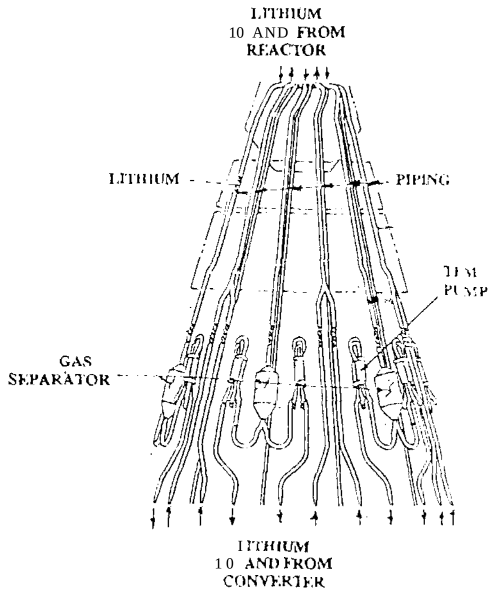

Figure 1. 100 kWe Space Reactor Power System Heat Transport Subsystem Components

Functional Requirements

Based on the above description, the following functional requirements were established for the space power gas separator/accumulator:

1. The residual gas void fraction in the lithium flow must be less than 0.001.

2. The maximum gas bubble size allowed to pass through shall be less than 0.1 of the fuel pin spacer wire diameter.

3. The gas separation shall take place where the helium solubility is lowest, which is at the highest lithium temperature. The highest lithium temperature is the outlet of the space reactor between the reactor and the pump. The gas separation shall be performed with an in-line arrangement so that small amounts of residual gas are removed as soon as the flow starts.

4. Thermal expansions and contractions of the coolant shall be accommodated for the entire range of space power system operations.

5. The heat transport subsystem pressure shall be maintained at 65 kPa (9.5 psia) at the beginning of mission and 150kPa (22 psia) at the end of mission.

6. The total gas volume shall be sized such that the gas separation function is not degraded under any operational condition. This shall include the loss of function of one gas separator/accumulator.

The gas separator/accumulator design concept is shown in Figure 2. The gas separator consists of four major components: a containment vessel, swirler guide vanes, a filter screen and a gas storage screen. The containment vessel is welded to the piping and contains the lithium coolant under all conditions. The swirler guide vanes induce centrifugal force in to the lithium/gas flow stream which causes the lower density gas to accumulate toward the center axis. Bubbles with diameters greater than one millimeter will naturally migrate inward due to the centrifugal acceleration. All coolant flow must then pass through filter screen pores that will prevent 100% of the bubbles that are 200 micron or larger from flowing through the screen. These trapped bubbles will gradually coalesce into larger bubbles and be drawn into the storage screen

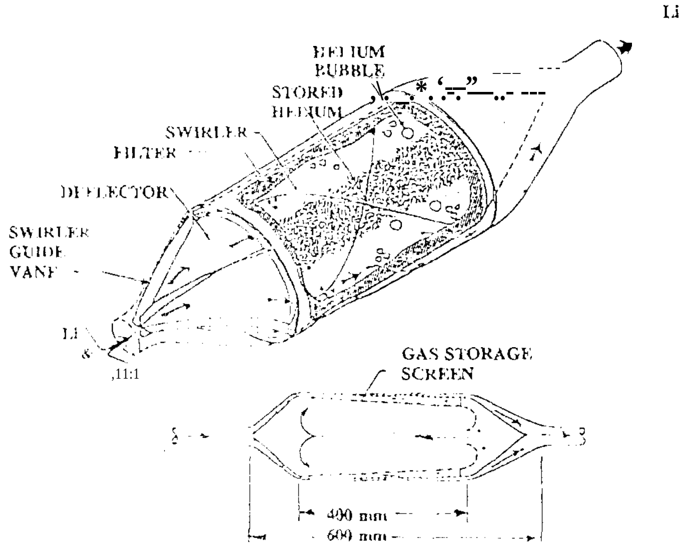

Figure 2. Gas Separator/Accumulator

GAS SEPARATOR DESIGN AND DEVELOPMENT

The gas separator/accumulator for the space power system has an outside diameter of 22.5 centimeters. The filter section is 40 centimeters long, and the overall device length is approximately 65 centimeters. The full-flow pressure drop is only 2 kPa (0.3 psia) greater than that of a straight section of pipe of the same length. The gas separator/accumulator are arranged in counter-rotating pairs, such that any unbalanced forces in space will be minimized

The gas separator/accumulator volume in one unit is about 20 Liters. At full power operation, the helium gas occupies only 32% of the total available. volume. At lower power levels, the primary loop temperatures are also lower and the lithium coolant contracts accordingly. At standby power, (10% of full thermal power) accumulated gas occupies about 56% of the available volume. At the freezing point of lithium, the gas volume is less than 6470 of the. total available.

Gas Separator Design

A gas separator/accumulator was designed to remove helium from lithium in zero gravity. Using the helium-lithium analysis codes, but substituting the properties of air for helium and water for lithium, a room temperature gas separator was designed, fabricated, and tested both horizontally and vertically against gravity. The device separated air from water even against gravity as predicted by the analyses. A design to separate helium from lithium was completed based on the air/water tests.

The. gas separator/accumulator (GSA) separates helium gas from liquid lithium. The helium gas generated in the lithium by irradiation in the reactor is 12 liters (at 150 kPa and 1375 K) for a 20 kWe power operating for 7.3 years at full power. The two GSAS in the 20 kWe system are initially filled with argon gas. Helium dissolved in the lithium will diffuse into the argon gas space inside the GSAs, preventing the. formation of large helium bubbles in the. lithium liquid. Bubbles larger than 200 microns will be separated and stored in the GSAs; bubbles smaller than 2.00 microns do not affect system operation. The gas storage screen ensures gas storage: during reverse flow, as well as forward flow conditions.

The GSAS maintain the lithium pressure at 65 kPa at the beginning of mission and at 150 kPa at the end of mission and accommodate lithium expansion and contraction. Two GSAs have a 40 liter capacity, providing adequate margin for the 12 liter generated in the 20 kWe system design. The initial charge of argon gas in each GSA is contained by a rupture. disk. The rupture disk is opened during lithium fill by raising the lithium pressure over the disk rupture pressure.

The key dimensions of one GSA for the space power system application are:

- Overall length: 650 mm
- Filter section length: 400 mm
- Filter Section, ID: 220 mm
- Containment vessel wall thickness: 1.0 mm
- Inlet diffuser length: 150 mm
- Outlet nozzle length: 100 mm
- Separation filter pore size: 0.1 mm
- Gas storage screen opening: 0.5 mm

Gas Separator Development

Various fabrication options for the gas separator/accumulator filter were considered: wire screen, laser drilled plate, mechanical drilling/punching of holes on a plate, chemical etching of holes on a plate, and sintered porous plate. The material for the gas separator/accumulator filter is Niobium-1% Zirconium-0.1 % Carbon. Of all these options, wire screen was considered the. most feasible and economical. Laser drilling of a 0.25 mm (0.010 inch) thick plate can also be done, but the cost to develop and to fabricate is substantially higher than the wire screen. Mechanical drilling/punching of a 0.25 mm (0.010 inch) plate is even more expensive. The chemical etching of 0.1 mm (0.004 inch) holes on a 0.?5 mm (0.010 inch) plate is not recommended because the depth to diameter ratio of the hole is too high. Sintered porous plate is heaviest of all options, and mechanical strength is difficult to achieve with a thin plate.

A special type of wire screen called the twilled dutch weave screen was selected for GSA application, and Figure 3 shows the twilled dutch weave screen geometry. This particular type of screen produces relatively small size holes and is mechanically strong. Two different samples of the twilled dutch weave screen were procured and tested for particle retention.

The test was conducted by trying to pass glass beads of known sizes through the screens. The test results are summarized in Table 1 The test data indicates that these two particular screens can retain particles larger than 200 microns, and theoretical

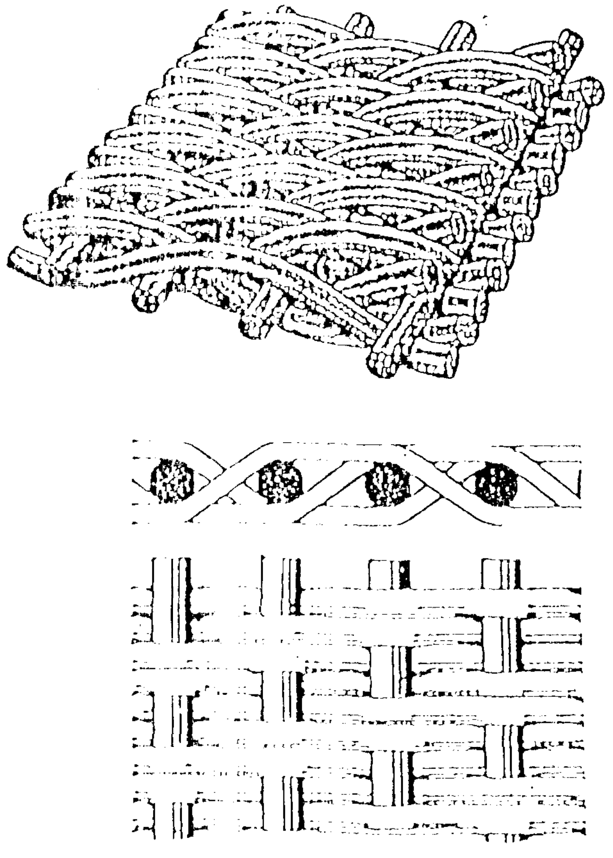

Figure 3. Twilled Dutch Weave

calculation supports the results. However, this is approximately twice as large as the vendor advertised value.. The vendor

Table 1. Screen Retention Results

Description		20 X 200 screen	20 x 250 screen
WIRE Size (mm)	(Warp)	0.279	0.254
	(Shute)	0.254	0.216
Particle Retention Size Per Vendor, (micron)		110	80
% Passed for Various Sizes of Micro-spheres Used	50 micron	100%	100%
	80 micron	100%	100%
	110 micron	100%	100%
	200 micron	0%	0%
Theoretically Calculated Min. Particle Retention Size, micron (mil)		239 (9.4)	221 (8.7)

advertised value may have been defined based on a different application than GSA type of applications. Fifty, eighty, and one hundred ten micron diameter glass beads all passed through this screen, but two hundred micron diameter glass beads would not pass through the screens. The impact of the larger particle retention size of the screen was evaluated and the following conclusions were drawn. For the space reactor power gas separator km-year systems, 200 microns (8 mils) is smaller than the smallest flow passages in the reactor core (1.62 mm or 65 roils) or in the converter heat exchanger (1.25 mm or 50 mils). The screen wire. size of 254 microns (10 roils) or larger would ensure a ten year life for a 20 kWe space power systems. For any particular missions which may require the. smallest flow passages less than 200 microns, smaller wire. size such as 125 microns (5 roils) may be used to reduce the minimum particle retention size from 200 microns to 100 microns with short screen life.

The filter bubble breakthrough pressure was calculated for the above two screens. 'l'his calculation shows that it requires 2.7 kPa (0.39 psia) for 20 x 200 screen and 2.9 kPa (0.42 psia) for 20 x 250 screen for the gas to pass through the screen. The expected pressure drop across the GSA filter screen at the rated flow is on the order of 0.07 kPa (0.01 psia). Further analysis shows that any gas bubble slightly larger than the minimum particle retention size is separated by the screen due to low screen pressure drop compared to the bubble. breakthrough pressure. The screen samples were tested by Yahalom, et al (1991) in a clear plastic tube with water/air. The purpose. of the water/air test is to confirm the results of the particle. retention test by glass beads, and to prepare the testing method for static lithium tests. In water/air test, the bubble behaviors and the screen bubble breakthrough were visually confirmed, and the visual observations were then correlated to the pressure drop measurement across the screen. In static lithium test, no visual observations can be made.

AIR/WATER TESTS

A gas/liquid separator was designed and fabricated in accordance with design analysis codes which predicted the separation of air from water. The separator/accumulator design was tested with air and water, and the experimental results, discussed by Pluta (1993), verified the analytical predictions. These same analytical codes with the properties of helium and lithium were used to determine the. separator design parameters for a 20 kWe space reactor power system. The space separator would then be built according to the design and demonstrated in a test loop with helium being injected in the lithium. The lithium 7 that is specified as the flight reactor coolant was irradiated in a fast test reactor, and the ir radiation results verified the analytically predicted helium generation rate.

TERRESTRIAL APPLICATIONS

The space gas/liquid separator has several practical applications for industrial use. There are several U. S. companies investigating the use. of this space technology for their businesses. These terrestrial application are a direct result of a new technology that was developed fnr a space power system.

Beverage Business

Coke syrup is packaged and distributed in plastic containers. While removing the coke syrup in order to mix the syrup with carbonated water, the coke syrup gets air bubble.s which changes the mixing ratio. So the beverage industry is investigating the development of a terrestrial air/coke syrup separator based on the space gas separator technology described above. The air/coke syrup separator design is a simple in-line separator that remove air from coke syrup just prior to mixing the syrup with carbonated water.

The beverage industry often aerates water to purify the water. This process leaves air in the water. The air must be remove from the purified water prior to carbonating the water. The beverage industry is investigating the development of the space gas/separater technology for an in line air/water separator in their water purification process.

Commercial Steam Powerplants

The space gas/liquid separator technology is also being investigated for large cc, mmercial steam powerplants to deaerate the water before and after the feedwater heaters. Removing the air before. the feedwater heater makes the heat transfer in the feedwater heater more effective, increases the operating life one of the feedwater heaters and increases the commercial powerplant efficiency in producing electricity. Removing the air from the water after the feedwater heater increases the heat transfer effectiveness in the boiler, the boiler lifetime and also increase the efficiency of commercial powerplants.

Commercial steam powerplants use existing less effective deaerators today. However, the existing deaerators have been manufactured and used for many years and are relatively inexpensive. Therefore it requires a utility and a powerplant component manufacturer to invest in the development of this component based on the. net return in increased revenue from the sale of electricity. At present a component manufacturing company is working with utilities to obtain their interest in determining the. benefits of developing and using, air/water separator based on the space gas/liquid separator technology. If economically promising the manufacturer will develop the air/water separator and the utilities will use this technology to improve *their* powerplant efficiency and reduce the cost of electricit y,

Industrial Plants and Equipment

Another potential application is to use the. gas/liquid separator and wet chemistry 10 remove all the gases from the air that is discharged from the plant processes and equipment and exhaust clean air to the. atmosphere from the their plant One company is in the, process of developing a gas separator for this purpose. The company built a gas separator model and duplicate the removal of air from water as described for the space separator development above. The company plans to develop, build and demonstrate the air purification function of a gas separator in their own plant and on their equipment. This company plans, to show zero rrir pollutants exhausted from their plants and equipment based on the gas separator technology. Once demonstrated the company plans to build and market the. separators based on the plant and equipment as an operating example.

Nitrogen Gas Industry

An additional terrestrial application that resulted from this space gas/liquid separator technology, is separating liquid carbon dioxide from nitrogen gas. This application is opposite from the space application in that it is removing a liquid from a gas rather than a gas from a liquid. However, the, company took the space technology idea rind is successfully using surface tension properties to separate small amounts of liquid carbon dioxide from very large now rates of nitrogen gas,

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