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THERMOELECTRIC HEAT PUMP AS A MEANS OF IMPROVING EFFICIENCY OF WATER PURIFICATION SYSTEMS ON SPACE MISSIONS

The paper presents the results of development and test of a modernized high-performance apparatus for water supply to cosmonauts during long-term missions. The basic structural units of the device include a centrifugal vacuum distiller (CD) and a thermoelectric heat pump (THP). The productivity is up to 5 l/hour, specific energy consumption is less than100 W·hour/l, the degree of water recovery from the source liquid is at least 92 %. The apparatus was created by the efforts of Thermodistillation Co. and Altec-M Ltd. The research was performed by the National Technical University of Ukraine "Kyiv Polytechnic Institute" and Institute of Thermoelectricity. Testing of the apparatus on the test facilities of Honeywell International and NASA has shown that the use of thermoelectric heat pump reduces energy expenditure by a factor of 1.6 as compared to closest competing device, i.e. vapor compression distiller (VCD). In so doing, CD and THP system work stably with concentration level to 77 %.

Key words: space flights, centrifugal distiller, thermoelectric heat pump, energy efficiency.

Introduction

Water supply to human crew on long-term space missions is a serious and relevant problem due to impossibility of its on board delivery during the flight. The problem was solved by water recovery from cosmonauts' liquid waste products – urine, sweat, service and sanitary water [1-3].

At the present time, there are several technologies of liquid waste purification. Depending on the degree of water contamination, use is made of ionic exchange, electrodialysis, a reverse osmosis and thermal distillation. Ionic exchange and electrodialysis are used at low concentrations of salts $5\cdot10^2 – 5\cdot10^3$ mg/l. To perform a reverse osmosis at desalination of highly mineralized water or urine, it is necessary to employ high pressure pumps (up to 70 bars) and make a pretreatment of the source liquid. The disadvantage of this method is a restricted service life of membranes. The technology of water purification through use of phase transition (distillation) offers the greatest promise, since it is free from the above disadvantages. The strong point of this method is independence of water purification quality of the degree of mineralization and contamination of the source liquid.

US specialists developed three systems of such water purification, namely AES system – liquid evaporation on wick modules using hot air, TIMES system – liquid evaporation on porous membranes using a thermoelectric heat pump and VCD system – centrifugal vapor compression distiller [4].

Since 1974 the National Technical University of Ukraine "Kyiv Polytechnic Institute" has developed distillers with a rotating surface on which evaporation occurs in a thin film [5-7]. During

1999 – 2005 Thermodistillation Co., Honeywell International Inc. (USA) and Institute of Thermoelectricity have jointly manufactured a new model of five-stage centrifugal distiller CD-5 with a thermopile as a heat pump (THP) [8-12]. The apparatus efficiency was tested on the NASA facilities during 2006 – 2009. The results of testing centrifugal distillation systems equipped with thermoelectric heat pumps are given below.

Multi-stage distillation apparatus with a thermoelectric heat pump

The method of improving the efficiency of distillation devices through use of multi-stage evaporation process is common nowadays. Its principle is that the secondary steam of one evaporation stage is used by the heating steam in the next stage. Pressure in each subsequent stage is maintained lower than in the previous one. *N*-stage distiller gives almost *n*-fold reduction of energy expenditures as compared to a single-stage distiller.

The cascade system is schematically shown in Fig. 1 [13]. Liquid to be purified is fed to a multi-stage vacuum rotor distiller (CD) where its evaporation and condensation take place. The necessary energy is transferred from the heat pump. Here the distilled water is cooled, and the purified liquid is heated. Both fluxes are directed by pumping with CD to heat pump circulation channels and come back to CD. The temperatures are from 35° to 45 °C.

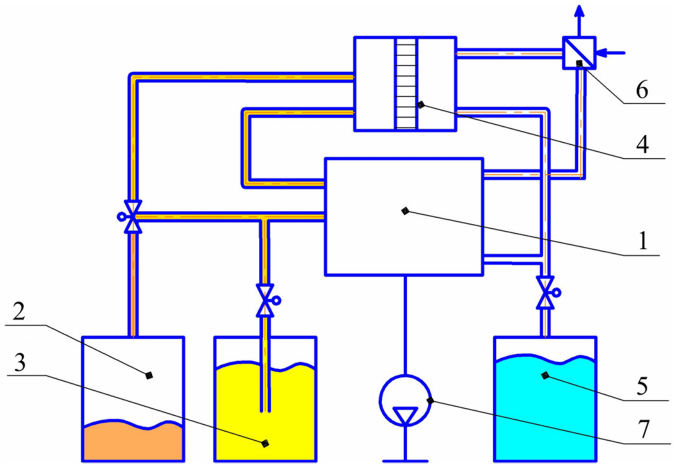

Fig. 1. Schematic of centrifugal distillation with a thermoelectric heat pump. 1 – cascade distiller CD, 2 – concentrate container, 3 – source liquid container, 4 – thermoelectric heat pump, 5 – purified water container, 6 – cooler, 7 – vacuum pump.

During a periodic cycle, 10 liters of the source liquid are processed. Purification yields 9 liters of purified water and one liter of brine.

Thermoelectric heat pump

“Altec-7001” thermopile based on the Peltier and Joule effects serves as a heat pump [10]. It assures heat removal from one object and transfer of this heat together with the Joule heat to another object. The outward appearance of “Altec-7001” thermopile is shown in Fig. 2. It comprises special liquid heat exchangers, thermoelectric modules and liquid collectors forming motion of liquids along the heat exchangers. The heat exchangers meet high technical requirements, namely they must possess low thermal resistance and, on the other hand, must be made of materials resistant to aggressive liquids. Such materials generally possess increased thermal resistance.

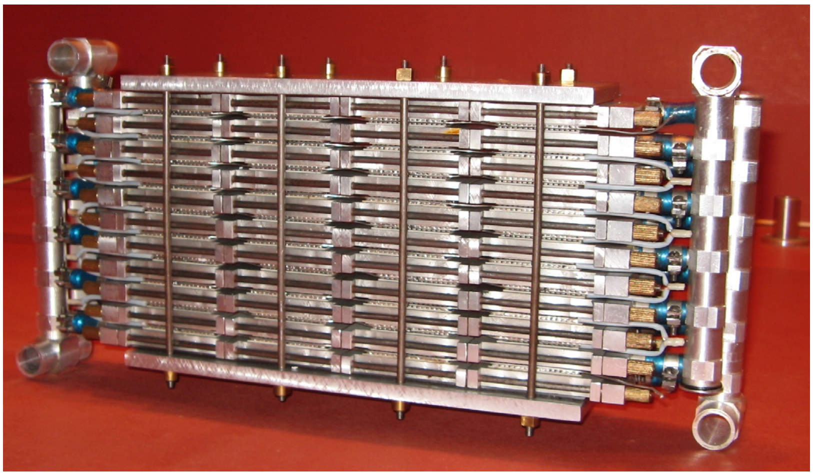

Fig. 2. Outward appearance of "Altec-7001" thermopile

Design optimization of heat exchangers was done by computer simulation. This resulted in heat exchanger designs consisting of titanium tubes and aluminum heat concentrators embracing them. To assure a turbulent mode of liquid motion, spiral titanium inserts are mounted into titanium tubes. Heavy demands are imposed on thermoelectric modules, especially as regards reliability. In order to increase the heat pump service life, the module components were connected into parallel-in-series circuits, increasing mean time between failures (MTBF) hundreds of times.

The basic technical characteristics of thermoelectric heat pump are given in Table 1.

Table 1

Basic technical characteristics of "Altec-7001" thermopile

Parameter	Value
Overall dimensions (length / width / height), mm	410/125/160
Mass, kg	6.1
DC electric voltage, V	12 – 30
Maximum electric power, W	500
Efficiency factor (max)	2.5
Hydraulic resistance in cooling circuits, bar in cooling circuit in heating circuit	< 0.20 < 0.15
Operating mode	continuous
Processed liquids	urine, sewage water

Long-duration test of CD-5 centrifugal distiller with "Altec-7001" thermopile was performed on the NASA test facility for 2006 – 2009. The test was performed on two solutions (Table 2). Altogether, 1500 kg of sewage water were processed.

To estimate the quality of distillation, comparative rests were performed at two NASA centers. At Marshall Space Flight Center (MSFC), Wiped-Film Rotating Disk (WFRD) (also centrifugal distiller with a vapor compressor) and Vapor Compression Distillation (VCD) systems were tested; at Johnson Space Center (JSC) - Cascade Distillation Subsystem (CD-5).

Table 2

Results of testing CD-5 centrifugal distiller with "Altec-7001" thermopile

Parameter	Test on solution № 1	Test on solution № 2
Solution composition	56.6 % condensed water 43.3 % urine	18.3 % condensed water, 14.0 % urine 67.7 % water for sanitary needs
Amount of processed liquid, kg	381	1198
Productivity, kg/hour	4.1 ± 0.1	5.2 ± 0.1
Regeneration degree, %	93.4 ± 0.7	90.3 ± 0.5
Specific energy consumption, W·h/kg	99 ± 6	106 ± 2

Table 3 compares the basic characteristics of centrifugal distillation systems CD-5, VCD and WFRD. The CD-5 distiller has lower specific energy consumption as compared to VCD with a higher, up to threefold, productivity and a larger recovery degree (90 – 94 and 89 %, respectively).

Table 3

Specification figures of tested distillers at recovery of solution № 1

	CD-5	VCD	WFRD
Productivity, kg/hour	3.7	1.63	16.1
Specific energy consumption, W·h/kg	109	188	85
Average power, W	375	297	1252

Distillate obtained using CD-5 without any post treatment [15] confirmed excellent quality and full conformity to standards. The quality of distillate obtained from VCD and WFRD, is inferior to that from CD-5 by factor of 2 to 8 [14].

In the course of all tests on NASA, Honeywell and Thermodistillation test facilities (> 1000 hours), the thermoelectric heat pump has operated trouble-free, without deviations from the required parameters and characteristics.

Conclusion

The most promising systems of water recovery and purification for long-term manned space missions were analyzed. The developed and manufactured multi-stage centrifugal distillation system equipped with a thermoelectric heat pump was compared to closest analogs. In the most important figures, namely specific energy consumption, overall dimensions, weight and quality of distillate obtained, the CD-5 + THP system outperforms all known distillation and purification systems of space application.

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Submitted 20.12.2013.