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EVOLUTION OF CENTRIFUGAL DISTILLATION SYSTEM WITH A THERMOELECTRIC HEAT PUMP FOR SPACE MISSIONS

Part 2. Study of the variable characteristics of a multi-stage distillation
system with a thermoelectric heat pump

The work presents the results of testing a multi-stage (5 stages) centrifugal distiller (CD) with the use of a thermoelectric heat pump (THP) to reduce power consumption. In the experiments, measurements were made of the local (online) data of distillation system, such as the temperature of the liquids (initial and distillate), current production, total salt content, specific power consumption at different speeds of distiller rotor, THP power, and the degree of concentration. The total duration of the tests was more than 700 hours, the amount of processed liquid (NaCl and urine) was more than 2000 kg. The study of three distillers and two THPs and a comparison of their results showed their identity, which characterizes high quality workmanship of these devices. The obtained operating parameters (revolutions n and THP power) can be used to optimize the design and operating modes of the entire CD + THP system. Bibl. 28, Fig. 8, Tabl. 1.

Key words: thermoelectricity, heat pump, distiller

Introduction

In [1 – 7], information is given on a 3-stage distiller with a thermoelectric heat pump. [8-10] show the results of the development of a five-stage centrifugal distiller with THP and its testing at the benches of the distiller manufacturer - Thermodistillation, Ukraine, and the customer - Honeywell, USA. In the following years, from 2002 to 2015, several articles and reports [11 – 18] were published on CDS tests at the NASA bench during the concentration of various solutions. These results, as well as some methods for improving the performance of the CDS system, are described in more detail in [19 – 26]. A more detailed review of the works is given in the 1st part of the article [27].

The published results quite convincingly describe the uniqueness of the system for its use in the life

support system of manned spacecraft in long space missions and on the International Space Station. However, the majority of publications give the integral characteristics of the CDS operation, namely the production of the Gd system (in distillate), kg/h; specific power consumption SPC, W·h/kg; the degree of water recovery from the original (processed) liquid %; and some indicators of the quality of the water obtained.

To create a theoretical model of CDS with a view to further improve it and optimize the design of the centrifugal distiller and the system as a whole, the data available in the published literature are insufficient. Attempts at modeling CDS were made in [28]. For the development, without proof of their suitability, the authors used some relationships to calculate the heat transfer coefficient during condensation and evaporation and did not take into account the temperature depression that occurs when the initial solutions are evaporated in the distiller. In addition, the thermal resistance of the wall was not taken into account in the calculation of heat transfer, which, as will be shown in part 3 of our article, can make up to 30 % of the total heat transfer. All this leads to a distortion of such important factors in assessing the efficiency of a thermoelectric heat pump (THP) as the difference in the temperature of liquid flows at the inlet of the device Δt_{IN} and the average temperature of liquids in the device Δt_{AV} .

From the data presented in our report [8] it follows that at the same rotational speeds of the distiller rotor, with decreasing THP power, a decrease in the specific energy consumption at CDS is observed, which was also noted in our works [19, 20]. The effect of this factor on the efficiency of THP and the value of system SPC has not been studied in more detail.

An important parameter of the efficiency of CD + THP system is also the degree of recovery. The larger this value, the smaller the amount of residue. In test trials of all works in the period from 1990 to 2017 there is no critical analysis of the possibility of achieving the maximum degree of recovery.

Experimental test bench for the study of integral characteristics of CD with THP

As already mentioned, in the period from 2000 to 2007, three identical five-stage centrifugal distillers were developed and manufactured by “TD” Co: the first one, in 2001, the second in 2002 and the third in 2006. Also, two thermoelectric heat pumps, developed and manufactured by the Institute of Thermoelectricity of the NAS and MES of Ukraine (ITE), were transferred to Honeywell International Inc. These devices were then tested in various versions at several test benches in the United States, including the NASA test bench.

Before shipment to the USA, the devices were tested at the “TD” Co. test bench.

Fig. 1 is a diagram of the test bench which was used by “TD” Co. for testing three distillers and two heat pumps.

The main and auxiliary equipment of the bench is combined by a system of pipelines that form two circulation circuits. In one of them (“hot”) the evaporated solution circulates, and in the other (“cold”) - distillate.

The test bench works as follows. The engine of the distiller 1 is switched on, providing given revolutions of the distiller rotor. The vacuum pump 7 sets the required pressure in the apparatus, which corresponds to the required boiling point of the solution. From the tank 13, the cold circuit is filled with distillate, in which the distillate is circulated through the distiller condenser 1, salimeter 9, rotameter 14, the cold side of the THP 2, heat exchanger-cooler 3 and again the distiller condenser. The “hot” circuit is filled from the tank 4 to the level set by the control valve 6. In the hot circuit, the solution circulates from the evaporator of the distiller 1 through the rotameter 14 to the hot side of the THP 2 and again to the evaporator of the distiller 1. When the electric power is supplied to the THP 2, the condensate is cooled in the “cold” circuit and the solution is heated in the “hot” circuit. The solution superheated in THP 2 relative

to the saturation temperature in the evaporator of distiller 1 partially evaporates, and the obtained steam is used as a heating agent in the next stage of distillation evaporation, the steam obtained in the last stage of the distiller is condensed in the contact condenser of distiller 1. Excess distillate from the cold circuit is automatically discharged into the distillate tank 5.

Valve 6 compensates with the fresh solution the evaporated part of the solution circulating in the hot circuit. At the same time, an increase in the concentration of dissolved substances occurs in it. Due to the fact that in THP 2 $Q_r = m_r \cdot c_{pr}(t_2 - t_1) > Q_x = m_x \cdot c_{px}(t_4 - t_3)$, to ensure the stationarity of the process, the excess heat is removed by the heat exchanger-cooler 3 to the environment.

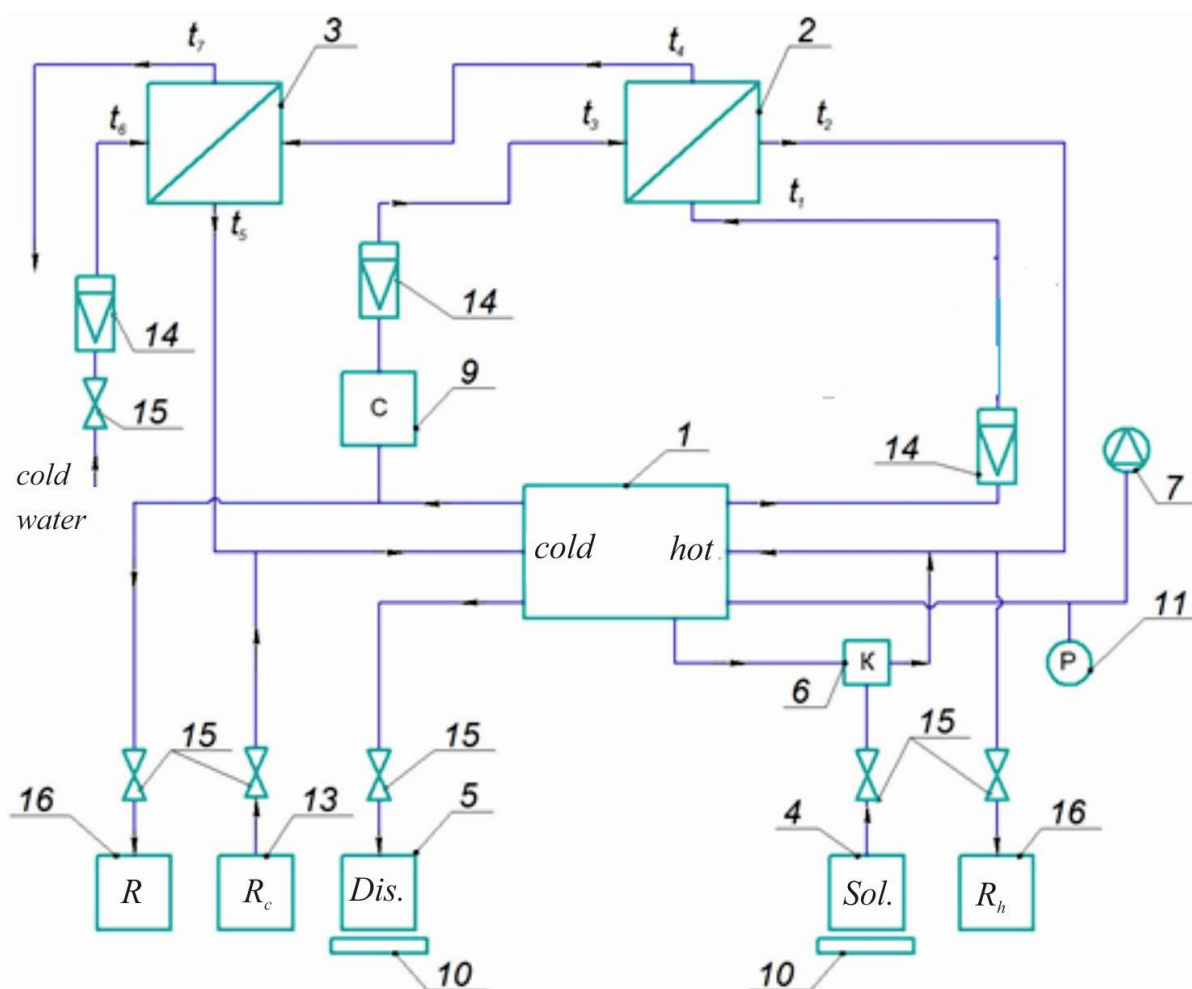


Fig.1. Diagram of the experimental test bench

- 1 – centrifugal vacuum distiller; 2 – thermoelectric heat pump;
 3 – heat-exchanger-cooler; 4 – outlet solution; 5 – distillate collector;
 6 – system power control valve; 7 – vacuum pump; 9 – salimeter; 10 – electronic balance;
 11 – vacuum gauge; 13 – distillate container for refueling; 14 – rotameters;
 15 – shut-off valve; 16 – circuit emptying containers.

After the experiment, the THP 2 power supply is turned off, and the cold and hot circuits are emptied into the corresponding containers 16.

The temperature was measured at the inlet and outlet of the thermal battery on the hot (t_1, t_2) and cold sides (t_3, t_4), behind the heat exchanger-cooler in the cold circuit (t_5) and at the inlet and outlet of the heat exchanger-cooler on the cooling side (t_6, t_7). The temperatures in the hot and cold circuits were measured with chromel-kopel thermocouples at an accuracy of ± 0.1 °C.

The pressure in the apparatus was measured with a vacuum gauge 11 with a measuring scale of -1 ... 0 bar (accuracy class 1.0) complete with a barometer.

The mass of the obtained distillate (product) and the initial solution was measured by electronic balance, the measurement accuracy of ± 2 g, the measurement range of ± 10 kg.

The salinity in the cold circuit was measured with a Hanna salimeter (0 ... 999ppm).

The drive power of the engine and heat pump was measured on the basis of voltmeters and ammeters, accuracy class 0.5. Revolutions were measured with a tachometer with an accuracy of ± 1 rpm.

Calculated values

Production in kilograms per hour:

$$G_d = \Sigma G_d / \Delta \tau, \quad (1)$$

where ΣG_d is the total mass of the obtained distillate in the tank 13, measured by the weights; $\Delta \tau$ is the measurement time interval.

Power consumption in watts for the main components of the CDS test product:

$$W = W_{THP} + W_{CD}, \quad (2)$$

where W_{THP} and W_{CD} is the average power consumed by THP and CD, respectively, over the period from the start to the stop of the distiller. The energy consumption of the vacuum pump was not taken into account at this stage.

Specific power consumption (SPC), W·h per kg of produced water:

$$SPC = W / G, \text{ W} \cdot \text{h} / \text{kg}. \quad (3)$$

Degree of recovery:

$$R = G_d / G_{in}, \quad (4)$$

where $G_{in} = \Sigma G_{in} / \Delta \tau$ is the mass of the consumed solution during the experiment, calculated by the weights in the tank 16.

Heat pump efficiency:

$$COP = Q_r / W_{THP}, \quad (5)$$

where $Q_r = G_r \cdot C_p (t_2 - t_1)$, W , G_r is flow rate of the liquid (solution) in the hot circuit; C_p is the average isobaric heat capacity of the solution, kJ/(kg·K).

Test results

Table presents a typical list of measured key indicators when concentrating urine.

Here, production stands for distiller capacity, TDS is total number of dissolved solids.

Typical table of measured values (urine, n=)1200 rpm

Time	Drive			THP			Weight		TDS	Flow		Product ion	SPC	Temperature			
	U	I	W	U	I	W	in	out	mg/l	hot	Cold			Hot in THP	Hot out THP	Cold in THP	Cold out THP
Min	V	A	W	V	A	W			mg/l	l/h		kg/h	W h/kg	°C			
0	24.2	3.1	75.0	20.5	10.08	206.6	0	0	12	60	82	0.00	0.0	23.2	23.1	22.9	22.9
6	24.2	3.1	75.0	22.5	10.9	245.3	288	184	22	60	82	1.84	174.1	31.8	43.7	23.4	22.7
12	24.2	3.1	75.0	28.5	14.3	407.6	634	602	38	60	82	4.18	174.1	37.5	48.3	24.5	22.4
18	24.2	3.1	75.0	29.2	14	408.8	1122	1070	51	60	82	4.68	103.4	38.7	49.4	25.1	22.3
24	24.2	3.1	75.0	32	14.4	460.8	1584	1528	61	60	82	4.58	117.0	38.8	50.8	25.1	22.0
30	24.2	3.1	75.0	31.8	15.2	483.4	2078	2006	67	60	82	4.78	116.8	39.4	51.5	25.2	22.1
36	24.2	3.1	75.0	32.3	14.22	459.3	2592	2502	73	60	82	4.96	107.7	40.0	52.2	25.4	22.1
42	24.2	3.1	75.0	32.1	15.24	489.2	3110	3004	76	60	82	5.02	112.4	40.0	52.2	25.4	22.3
48	24.2	3.1	75.0	31.9	15.2	484.9	3628	3500	79	61	82	4.96	112.9	40.1	52.1	24.9	22.0
54	24.2	3.1	75.0	32.4	15.36	497.7	4136	3990	82	61	83	4.90	116.9	40.3	52.2	25.1	22.1
60	24.2	3.1	75.0	33	15.6	514.8	4656	4492	84	62	83	5.02	117.5	40.7	53.5	24.9	22.0
66	24.2	3.1	75.0	33.2	15.64	519.2	5182	5006	87	62	83	5.14	115.6	40.9	53.2	24.9	22.1
72	24.2	3.1	75.0	33.1	15.56	515.0	5702	5508	90	63	83	5.02	117.5	40.9	53.1	24.9	22.0
78	24.2	3.1	75.0	33	15.58	514.1	6220	6010	92	64	83	5.02	117.4	40.9	53.2	24.9	22.0
84	24.2	3.1	75.0	33.2	15.72	521.9	6740	6510	94	65	83	5.00	119.4	41.0	53.5	24.8	22.0
90	24.2	3.1	75.0	33.2	15.46	513.3	7250	7010	96	67	83	5.00	117.7	41.0	53.5	24.8	22.0
96	24.2	3.1	75.0	32.8	15.34	503.2	7755	7500	97	68	83	4.90	118.0	41.0	53.1	24.6	22.0
102	24.2	3.1	75.0	32.9	15.4	506.7	8175	8000	98	71	83	5.00	116.3	41.0	53.1	24.8	22.0
108	24.2	3.1	75.0	0	0	0.0	8280	8205	96	71	83						
Average	24.2	3	75.0			492.8	8280	8205	75			4.93	115.1				
Total																	

Table

The identity of performance of three models of multi-stage centrifugal distillers with two THPs

Figs. 2 and 3 show the results of the concentration of urine from three distiller models with a heat pump power of $N = 400$ W and a rotational speed of 1200 rpm for 60 minutes. It can be seen from the figures that the production G_d and the specific power consumption SPC of all three samples of centrifugal distillers are close. The discrepancy of data on these indicators at the same time τ does not exceed 5 %.

This result allows us in the further analysis of the results of the various tests not to indicate the distiller number.

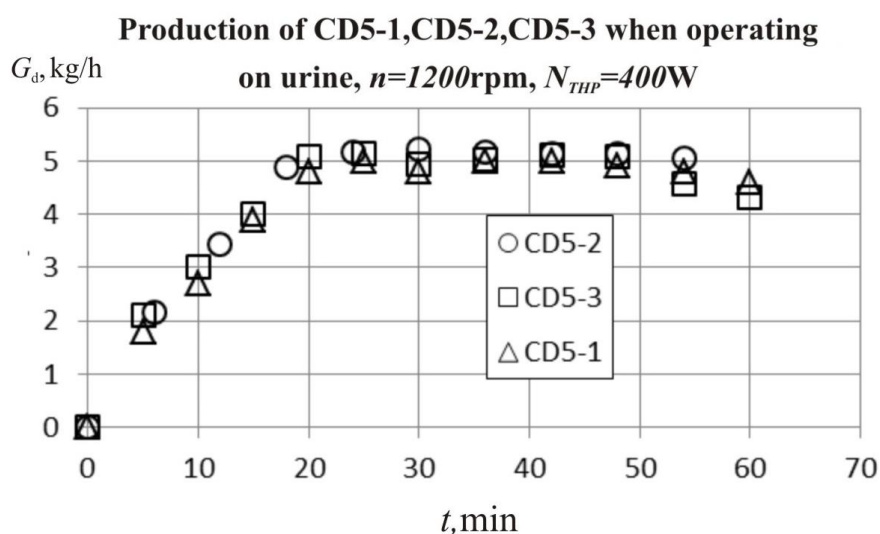


Fig.2 Time dependence of production for different distillers

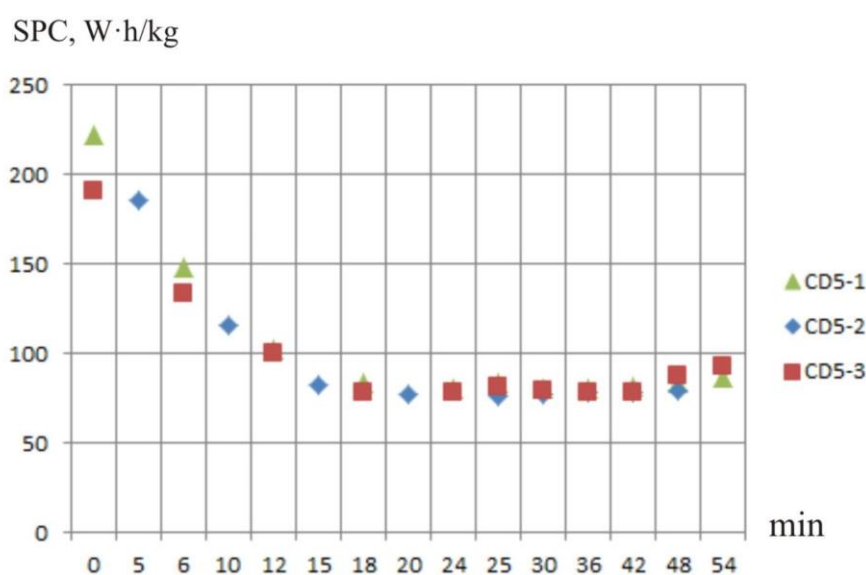


Fig.3 Time dependence of specific power consumption for different distillers,
 $W = 400$ W (without account of engine)

The identity of the THP is shown in Fig. 4, from which it follows that when operating on the same sample of the CD5-3 distiller with different heat pumps THP-1 and THP-2, the production with the same heat pump power is identical.

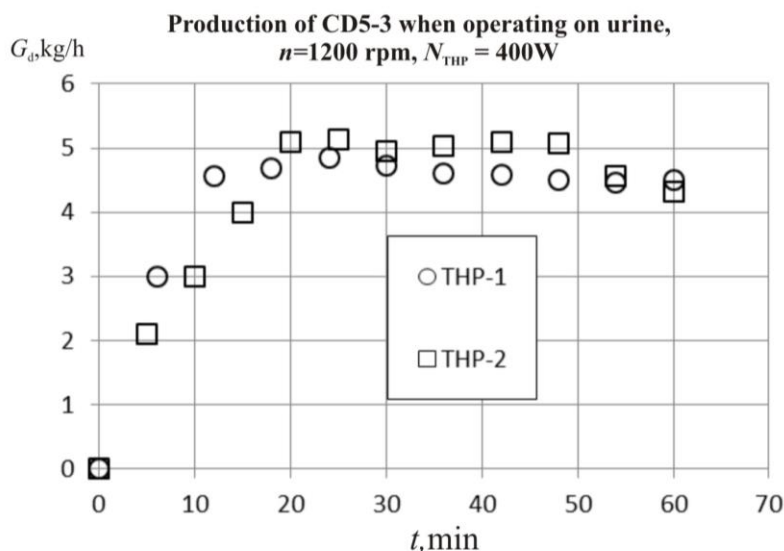


Fig.4. Time dependence of system production for two samples of thermoelectric heat pumps

Temperatures

Fig. 5 shows temperature change in online mode when processing urine with the initial concentration $C = 5 \%$, rotations $n = 1100 \text{ rpm}$ and heat pump power $N_{\text{THP}} = 400 \text{ W}$.

After turning on the distiller, after 10 minutes, the temperatures of the liquids in the hot and cold circuits reach the operating value.

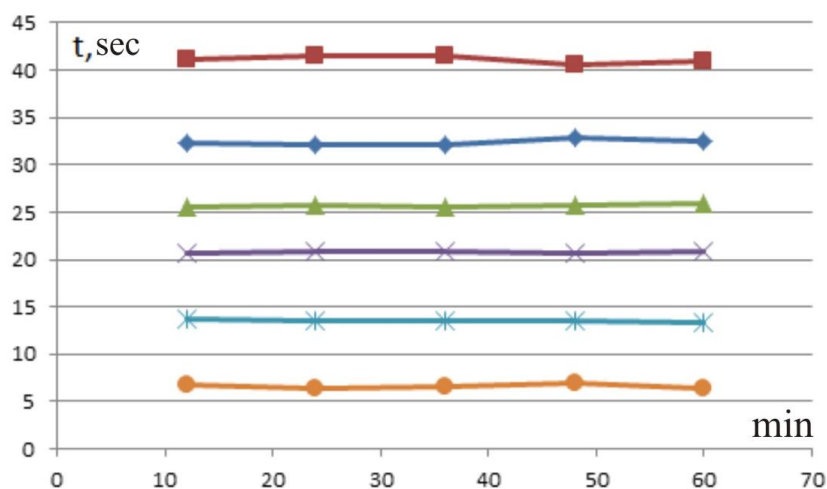


Fig.5a The dependence of temperatures on the time of the experiment (Water)

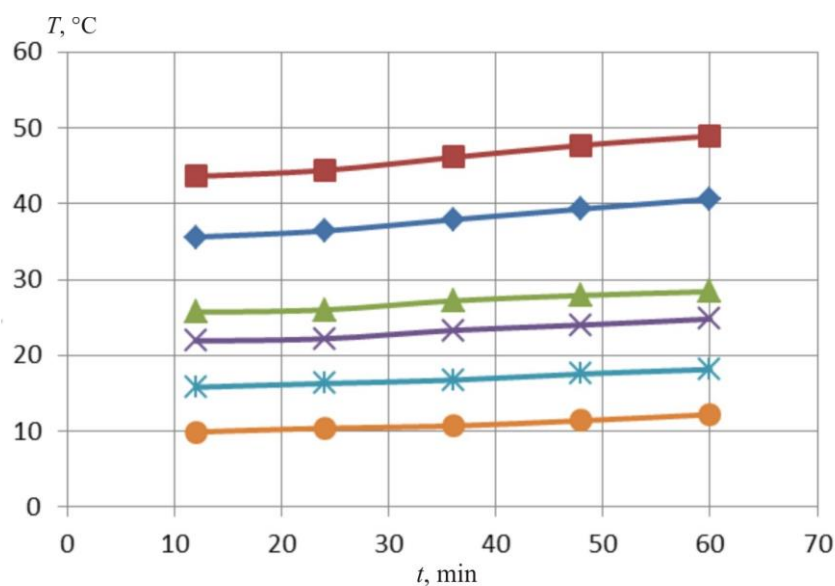


Fig.5b The dependence of temperatures on the time of the experiment (Urine)

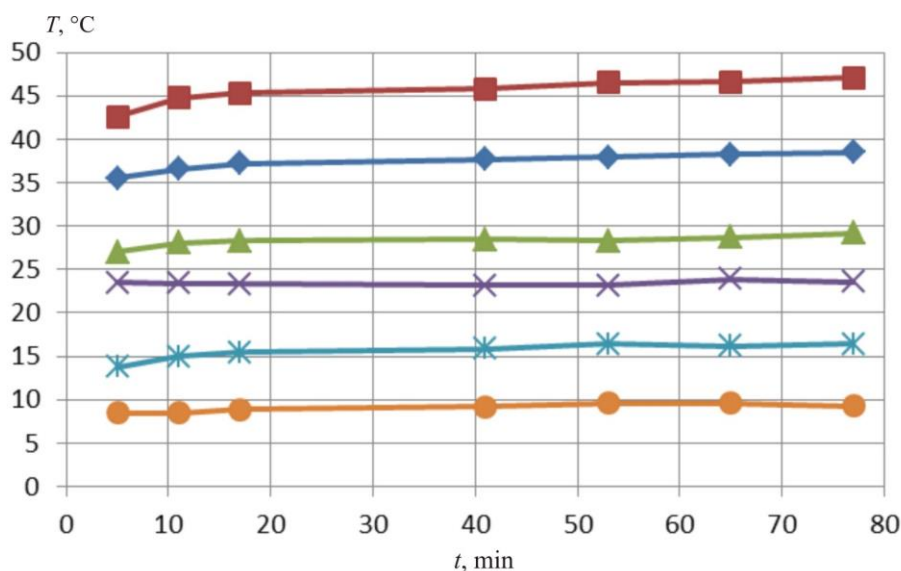


Fig.5c The dependence of temperatures on the time of the experiment (NaCl)

- hot-in solution temperature at the inlet to the heat pump in the “hot” circuit (t_1), °C;
- hot-out solution temperature at the outlet of the heat pump in the “hot” circuit (t_2), °C;
- cold-in distillate temperature at the inlet to the heat pump in the “cold” circuit (t_3), °C;
- cold-out distillate temperature at the outlet of the heat pump in the “cold” circuit (t_4), °C;
- Δt^- average temperature head at the heat pump, $\Delta t_{av} = 0,5(t_1 + t_2) - 0,5(t_3 + t_4)$, °C;
- Δt_{in} average temperature head at the inlet to the heat pump, $\Delta t_{in} = t_1 - t_3$, °C;

When concentrating a NaCl solution and urine, the temperatures in the hot circuit increase throughout the experiment due to an increase in the physical-chemical temperature depression during

evaporation. In turn, this increases the overall average temperature head at the heat pump (Δt_{av}) and the average temperature head at the inlet to the heat pump (Δt_{in}), which affects the efficiency of the heat pump.

Production

It can be seen from Fig. 6 that when $NaCl$ and urine are concentrated, the production is lower than that obtained when working on the distillate and decreases during the experiment due to an increase in temperature depression.

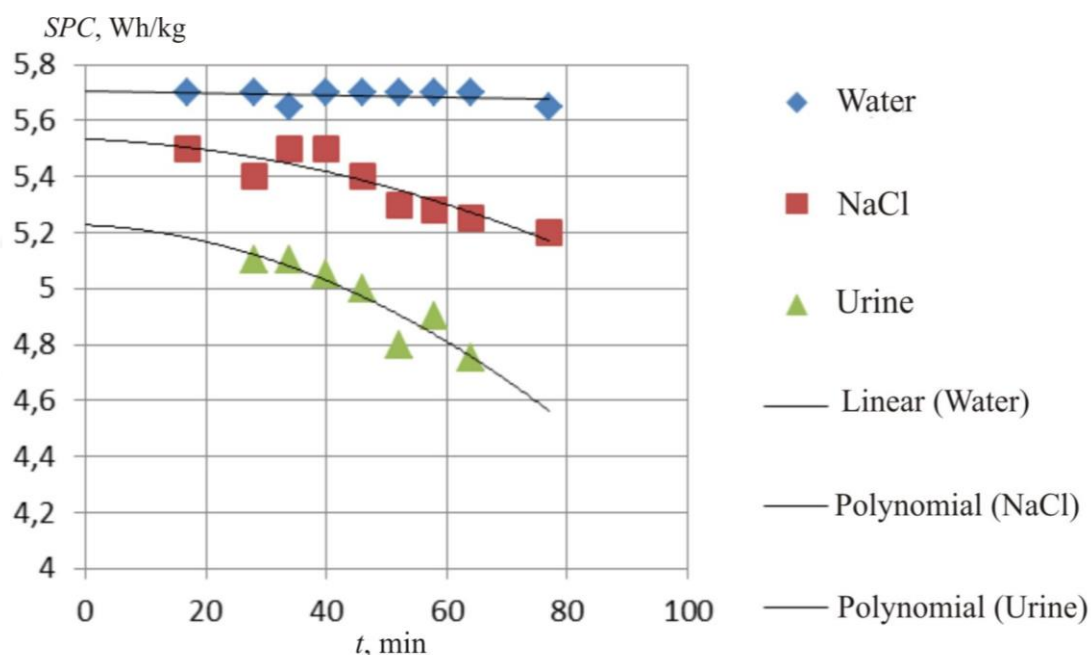


Fig. 6 The production of the distiller depending on the type of processed solution ($n = 1100$ rpm; $N = 400$ W).

Figure 7 shows the effect of heat pump power on the production of the distiller. The experiments were performed on urine at the same distillation speed ($n = 1000$ rpm). The amount of distillate obtained in all experiments was 5 kg, which corresponded to recovery ≈ 0.9 . The greater the power of the heat pump, the higher the system production. In so doing, for each power in the initial 15 minutes there is an increase in the production (the device enters the operating mode), after which, due to an increase in the concentration of the solution in the hot circuit, the temperature depression increases and the production decreases. At the same time, the higher the power, the greater effect on the production is produced by temperature depression.

At the same time, as can be seen from Fig. 8, the higher the power supplied to the heat pump, the higher the specific energy consumption for producing one kg of distillate. Thus, from an energy point of view, it is more efficient to work at low heat pump powers.

In all tests performed, the quality of the obtained distillate met all the requirements to potable water. When processing $NaCl$, TDS in the “cold” circuit did not exceed 10 ppm. When processing urine, TDS < 100 ppm; COD (chemical oxygen demand) < 15 mg/l; ammonia $NH_3 + NH_4$ < 5 mg/l.

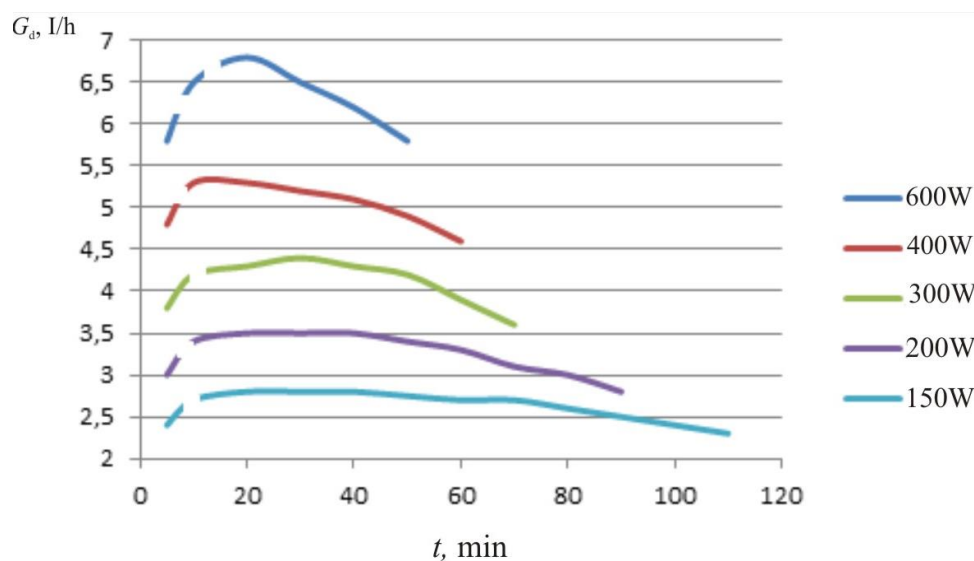


Fig. 7 Effect of heat pump power on the distiller production ($n = 1000$ rpm)

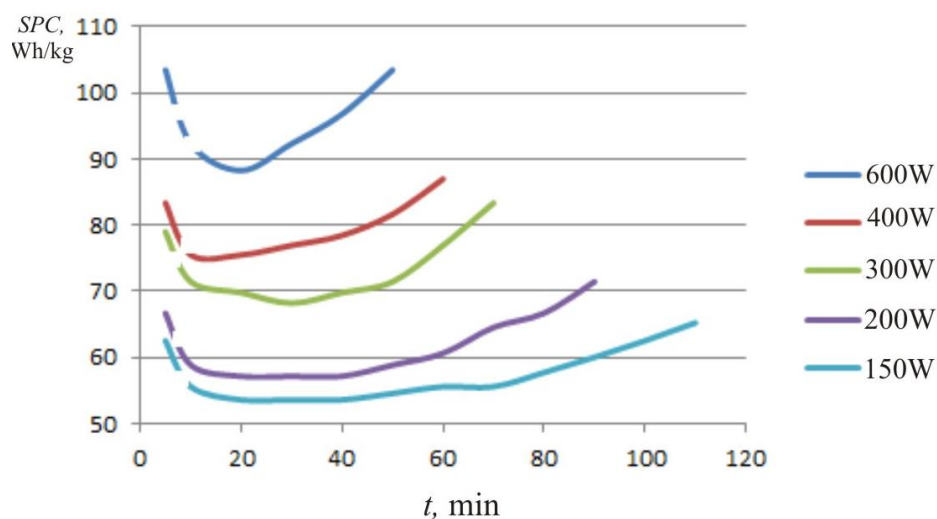


Fig. 8 Effect of heat pump power on the specific power consumption of the distiller without account of engine power ($n = 1000$ rpm)

Conclusions

1. This paper presents the results of measuring local parameters of distillation system (temperature in the “hot” and “cold” circuits, production, specific power consumption, TDS) in online mode with a change in testing time from 30 to 200 min, rotation speed $n = 800 \dots 1200$ rpm, NTHP = 150...600 W.
2. The identity of three manufactured multi-stage centrifugal distillers with 5 stages and 2 thermoelectric heat pumps is shown.
3. A decrease in SPC with a decrease in NTHP both locally, i.e. at a certain value of time τ , and on the average for the concentration of urine and NaCl solution at the same speed and total amount of distillate obtained has been noted.
4. Measured in all the tests, the main characteristics of distillate quality TDS, NH₄, TOC meet the requirements to potable water.

References

1. Rifert V., Barabash P., Goliad N. (1990). Methods and processes of thermal distillation of water solutions for closed water supply systems. *SAE Paper 901249, 20th Intersociety Conference on Environmental Systems (Williamsburg, July 1990)*.
2. Samsonov N., Bobe L., Novikov V., Rifert V., et al. (1994). Systems for water reclamation from humidity condensate and urine for space station. *SAE Paper 941536, 24th International society Conference on Environmental Systems (June, 1994)*.
3. Samsonov N.M., Bobe L.S, Novikov V., Rifert V.G., Barabash P.A, et al (1995). Development of urine processor distillation hardware for space stations. *SAE Paper 951605, 25th International Conference on Environmental Systems (San Diego, July 1995)*.
4. Samsonov, N.M., Bobe, L.S, Novikov, V., Rifert, V.G., et al. (1997). Updated systems for water recovery from humidity condensate and urine for the international space station. *SAE Paper 972559, 27th International Conference on Environmental Systems (Nevada, July 1997)*.
5. Samsonov N.M., Bobe L.S, Novikov V., Rifert V.G., et al. (1999). Development and testing of a vacuum distillation subsystem for water reclamation from urine. *SAE Paper 1999-01-1993, 29th International Conference on Environmental Systems, 1999*.
6. Rifert V., Usenko V., Zolotukhin I., MacKnight A., Lubman A. (1999). Comparison of secondary water processors using distillation for space applications. *SAE Paper 99-70466, 29th International Conference on Environmental Systems (Denver, July 1999)*.
7. Rifert V., Stricun, A., Usenko, V. (2000). Study of dynamic and extreme performances of multistage centrifugal distiller with the thermoelectric heat pump. *SAE Technical Papers 2000. 30th International Conference on Environmental Systems (Toulouse; France, 10-13 July 2000)*.
8. Rifert, V., V. Usenko, I. Zolotukhin, A. MacKnight and A. Lubman (2001). Design optimisation of cascade rotary distiller with the heat pump for water reclamation from urine. (2001). *SAE Paper 2001-01-2248, 31st International Conference on Environmental Systems (Orlando, July 2001)*.
9. Rifert, V. G., Usenko V.I., Zolotukhin I.V., MacKnight A. and Lubman A. (2003). Cascaded distillation technology for water processing in space. *SAE Paper 2003-01-2625. 34th International Conference on Environmental Systems (Orlando, July 2003)*.
10. Lubman A, MacKnight A, Rifert V, Zolotukhin I. and Pickering K. (2006). Wastewater processing cascade distillation subsystem. design and evaluation. *SAE International, 2006-01-2273. July 2006*.
11. Lubman A., MacKnight A., Rifert V. and Barabash, P. (2007). Cascade distillation subsystem hardware development for verification testing. *SAE International, 2007-01-3177, July 2007*.
12. Callahan M., Lubman A., MacKnight A., Thomas H. and Pickering K. (2008). Cascade distillation subsystem development testing. (2008). *SAE International, 2008-01-2195, July 2008*.
13. Callahan M., Lubman A. and Pickering K. (2009). Cascade distillation subsystem development: progress toward a distillation comparison test. (2009). *SAE International, 2009-01 -2401, July 2009*.
14. Callahan M., Patel V. and Pickering K. (2010). Cascade distillation subsystem development: early results from the exploration life support distillation technology comparison test. *American Institute of Aeronautics and Astronautics, 2010-6149, July 2010*.
15. McQuillan Jeff, Pickering Karn D., Anderson Molly, Carter Layne, Flynn Michael, Callahan Michael, Vega Leticia, Allada Rama and Yeh Jannivine. Distillation technology down-selection for the exploration life support (ELS) water recovery systems element. *40th International Conference on Environmental Systems, AIAA 2010-6125 (Barcelona, Spain. July 2010)*.
16. Patel V., Au H., Shull S., Sargusingh M., Callahan M.. (2014). Cascade distillation system – a water recovery system for deep space missions. *ICES-2014-12, 44 International Conference on*

Environmental Systems (Tucson, Arizona, July 2014).

17. Loeftelholz David, Baginski Ben, Patel Vipul, MacKnight Allen, Schull Sarah, Sargusingh Miriam, Callahan Michael. (2014). Unit operation performance testing of cascade distillation subsystem. *44th International Conference on Environmental Systems, 13-17 July 2014 (Tucson, Arizona). ICES-2014-0014.*
18. Callahan Michael R., Sargusingh Miriam J. (2014). Honeywell cascade distiller system performance testing interim results. American Institute of Aeronautics and Astronautics.
19. Rifert V.G., Anatyshuk L.I., Barabash P.A., Usenko V.I., Strikun A.P., Prybyla A.V. (2017). Improvement of the distillation methods by using centrifugal forces for water recovery in space flight applications. *J.Thermoelectricity*, 1, 71-83.
20. Rifert Vladimir G., Barabash Petr A., Usenko Vladimir, Solomakha Andrii S., Anatyshuk Lukyan I., Prybyla A.V. (2017). Improvement of the cascade distillation system for long-term space flights. 68th International Astronautical Congress (IAC) (Adelaide, Australia, 25-29 September 2017). IAC-17-A1.IP.25.
21. Anatyshuk L.I., Prybyla A.V. (2015). Optimization of thermal connections in thermoelectric liquid-liquid heat pumps for water purification systems of space application. *J.Thermoelectricity*, 4, 45 – 51.
22. Anatyshuk L.I., Prybyla A.V. (2015). Optimization of power supply system of thermoelectric liquid-liquid heat pump. *J.Thermoelectricity*, 6, 53 – 58.
23. Anatyshuk L.I., Rozver Yu.Yu., Prybyla A.V. (2017). Experimental study of thermoelectric liquid-liquid heat pump. *J.Thermoelectricity*, 3, C. 33 – 39.
24. Anatyshuk L.I., Prybyla A.V. (2017). Limiting possibilities of thermoelectric liquid-liquid heat pump. *J.Thermoelectricity*, 4, 33 – 39.
25. Anatyshuk L.I., Prybyla A.V. (2017). The influence of quality of heat exchangers on the properties of thermoelectric liquid-liquid heat pumps. *J.Thermoelectricity*, 5, 33 – 39.
26. Anatyshuk L.I., Prybyla A.V. (2017). On the coefficient of performance of thermoelectric liquid-liquid heat pumps with regard to energy loss for heat carrier transfer. *J.Thermoelectricity*, 6, 33 – 39.
27. Rifert V.G., Anatyshuk L.I., Barabash P.O., Usenko V.I., Strikun A.P., Solomakha A.S., Petrenko V.G., Prybyla A.V. (2019). Evolution of centrifugal distillation system with a thermoelectric heat pump for space missions. Part 1. Review of publications on centrifugal distillation in the period of 1990 – 2017. *J.Thermoelectricity*, 1, 5–15.
28. Perry Bruce A., Anderson Molly S. (2015). Improved dynamic modeling of the cascade distillation subsystem and analysis of factors affecting its performance. *45th International Conference on Environmental Systems 12-16 July 2015 (Bellevue, Washington). ICES-2015-216.*

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ЕВОЛЮЦІЯ СИСТЕМИ ВІДЦЕНТРОВОЇ ДИСТИЛЯЦІЇ З ТЕРМОЕЛЕКТРИЧНИМ ТЕПЛОВИМ НАСОСОМ ДЛЯ КОСМІЧНИХ МІСІЙ

Частина 2. Дослідження змінних характеристик системи
багатоступінчастої дистиляції (СМЕД) з термоелектричним
тепловим насосом (ТНР)

У роботі наведені результати випробувань багатоступінчастого (5 щаблів) відцентрового дистилятора (СМЕД) з використанням для зниження енергоспоживання термоелектричного теплового насоса (ТНР). У досвідах заміряли локальні (у режимі он-лайн) дані системи дистиляції, такі як температура рідин (вихідної й дистиляту) продуктивність, що тече, загальний солеміст, питому витрату енергії при різних швидкостях обертання ротора дистилятора, потужності ТНР, ступінь концентрування. Загальна тривалість випробувань склала більш 700 годин, кількість переробленої рідини (NaCl і урини) склала більш 2000 кг. Дослідження трьох дистиляторів і двох ТНР і порівняння їх результатів показало їхню ідентичність, що характеризує висока якість виготовлення цих пристроїв. Отримані дані параметрів експлуатації (оберти n і потужність ТНР), можуть бути використані для оптимізації конструкції й режимів експлуатації роботи всієї системи СД + ТНР. Бібл. 28, рис. 8, табл. 1.

Ключові слова: термоелектрика, тепловий насос, дистилятор

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ЭВОЛЮЦИЯ СИСТЕМЫ ЦЕНТРОБЕЖНОЙ ДИСТИЛЛЯЦИИ С ТЕРМОЭЛЕКТРИЧЕСКИМ ТЕПЛОВЫМ НАСОСОМ ДЛЯ КОСМИЧЕСКИХ МИССИЙ

Часть 2. Исследование переменных характеристик системы
многоступенчатой дистилляции (СМЕД) с термоэлектрическим
тепловым насосом (ТНР)

В работе приведены результаты испытаний многоступенчатого (5 ступеней) центробежного дистиллятора (СМЕД) с использованием для снижения энергопотребления термоэлектрического теплового насоса (ТНР). В опытах замеряли локальные (в режиме он-лайн) данные системы дистилляции, такие как температура жидкостей (исходной и дистиллята), текущую производительность, общее солесодержание, удельный расход энергии при разных скоростях вращения ротора дистиллятора, мощности ТНР, степень концентрирования. Общая продолжительность испытаний составила более 700 часов, количество переработанной жидкости (NaCl и урины) составила более 2000 кг. Исследование трех дистилляторов и двух ТНР и сравнение их результатов показало их идентичность, что характеризует высокое качество изготовления этих устройств. Получены данные параметров эксплуатации (обороты n и мощность ТНР), могут быть использованы для оптимизации конструкции и режимов эксплуатации работы всей системы СД + ТНР. Библ. 28, рис. 8, табл. 1.

Ключевые слова: термоэлектричество, тепловой насос, дистиллятор.

References

1. Rifert V., Barabash P., Goliad N. (1990). Methods and processes of thermal distillation of water solutions for closed water supply systems. *SAE Paper 901249, 20th Intersociety Conference on Environmental Systems (Williamsburg, July 1990)*.
2. Samsonov N., Bobe L., Novikov V., Rifert V., et al. (1994). Systems for water reclamation from humidity condensate and urine for space station. *SAE Paper 941536, 24th International society Conference on Environmental Systems (June, 1994)*.
3. Samsonov N.M., Bobe L.S, Novikov V., Rifert V.G., Barabash P.A, et al (1995). Development of urine processor distillation hardware for space stations. *SAE Paper 951605, 25th International Conference on Environmental Systems (San Diego, July 1995)*.
4. Samsonov, N.M., Bobe, L.S, Novikov, V., Rifert, V.G., et al. (1997). Updated systems for water recovery from humidity condensate and urine for the international space station. *SAE Paper 972559, 27th International Conference on Environmental Systems (Nevada, July 1997)*.
5. Samsonov N.M., Bobe L.S, Novikov V., Rifert V.G., et al. (1999). Development and testing of a vacuum distillation subsystem for water reclamation from urine. *SAE Paper 1999-01-1993, 29th International Conference on Environmental Systems, 1999*.
6. Rifert V., Usenko V., Zolotukhin I., MacKnight A., Lubman A. (1999). Comparison of secondary water processors using distillation for space applications. *SAE Paper 99-70466, 29th International Conference on Environmental Systems (Denver, July 1999)*.
7. Rifert V, Stricun, A., Usenko, V. (2000). Study of dynamic and extreme performances of multistage centrifugal distiller with the thermoelectric heat pump. *SAE Technical Papers 2000. 30th International Conference on Environmental Systems (Toulouse; France, 10-13 July 2000)*.
8. Rifert, V., V. Usenko, I. Zolotukhin, A. MacKnight and A. Lubman (2001). Design optimisation of cascade rotary distiller with the heat pump for water reclamation from urine. (2001). *SAE Paper 2001-*

- 01-2248, 31st International Conference on Environmental Systems (Orlando, July 2001).
9. Rifert, V. G., Usenko V.I., Zolotukhin I.V., MacKnight A. and Lubman A. (2003). Cascaded distillation technology for water processing in space. *SAE Paper 2003-01-2625. 34th International Conference on Environmental Systems (Orlando, July 2003).*
 10. Lubman A, MacKnight A, Rifert V, Zolotukhin I. and Pickering K. (2006). Wastewater processing cascade distillation subsystem. design and evaluation. *SAE International, 2006-01-2273. July 2006.*
 11. Lubman A., MacKnight A., Rifert V. and Barabash, P. (2007). Cascade distillation subsystem hardware development for verification testing. *SAE International, 2007-01-3177, July 2007.*
 12. Callahan M., Lubman A., MacKnight A., Thomas H. and Pickering K. (2008). Cascade distillation subsystem development testing. (2008). *SAE International, 2008-01-2195, July 2008.*
 13. Callahan M., Lubman A. and Pickering K. (2009). Cascade distillation subsystem development: progress toward a distillation comparison test. (2009). *SAE International, 2009-01 -2401, July 2009.*
 14. Callahan M., Patel V. and Pickering K. (2010). Cascade distillation subsystem development: early results from the exploration life support distillation technology comparison test. *American Institute of Aeronautics and Astronautics, 2010-6149, July 2010.*
 15. McQuillan Jeff, Pickering Karn D., Anderson Molly, Carter Layne, Flynn Michael, Callahan Michael, Vega Leticia, Allada Rama and Yeh Jannivine. Distillation technology down-selection for the exploration life support (ELS) water recovery systems element. *40th International Conference on Environmental Systems, AIAA 2010-6125 (Barcelona, Spain. July 2010).* .
 16. Patel V., Au H., Shull S., Sargusingh M., Callahan M.. (2014). Cascade distillation system – a water recovery system for deep space missions. *ICES-2014-12, 44 International Conference on Environmental Systems (Tucson, Arizona, July 2014).*
 17. Loeftelholz David, Baginski Ben, Patel Vipul, MacKnight Allen, Schull Sarah, Sargusingh Miriam, Callahan Michael. (2014). Unit operation performance testing of cascade distillation subsystem. *44th International Conference on Environmental Systems, 13-17 July 2014 (Tucson. Arizona). ICES-2014-0014.*
 18. Callahan Michael R., Sargusingh Miriam J. (2014). Honeywell cascade distiller system performance testing interim results. American Institute of Aeronautics and Astronautics.
 19. Rifert V.G., Anatychuk L.I., Barabash P.A, Usenko V.I., Strikun A.P., Prybyla A.V. (2017). Improvement of the distillation methods by using centrifugal forces for water recovery in space flight applications. *J.Thermoelectricity*, 1, 71-83.
 20. Rifert Vladimir G., Barabash Petr A., Usenko Vladimir, Solomakha Andrii S., Anatychuk Lukyan I., Prybyla A.V. (2017). Improvement of the cascade distillation system for long-term space flights. 68th International Astronautical Congress (IAC) (Adelaide, Australia, 25-29 September 2017). IAC-17-A1.IP.25.
 21. Anatychuk L.I., Prybyla A.V. (2015). Optimization of thermal connections in thermoelectric liquid-liquid heat pumps for water purification systems of space application. *J.Thermoelectricity*, 4, 45 – 51.
 22. Anatychuk L.I., Prybyla A.V. (2015). Optimization of power supply system of thermoelectric liquid-liquid heat pump. *J.Thermoelectricity*, 6, 53 – 58.
 23. Anatychuk L.I., Rozver Yu.Yu., Prybyla A.V. (2017). Experimental study of thermoelectric liquid-liquid heat pump. *J.Thermoelectricity*, 3, C. 33 – 39.
 24. Anatychuk L.I., Prybyla A.V. (2017). Limiting possibilities of thermoelectric liquid-liquid heat pump. *J.Thermoelectricity*, 4, 33 – 39.
 25. Anatychuk L.I., Prybyla A.V. (2017). The influence of quality of heat exchangers on the properties of thermoelectric liquid-liquid heat pumps. *J.Thermoelectricity*, 5, 33 – 39.

26. Anatychuk L.I., Prybyla A.V. (2017). On the coefficient of performance of thermoelectric liquid-liquid heat pumps with regard to energy loss for heat carrier transfer. *J. Thermoelectricity*, 6, 33 – 39.
27. Rifert V.G., Anatychuk L.I., Barabash P.O., Usenko V.I., Strikun A.P, Solomakha A.S., Petrenko V.G., Prybyla A.V. (2019). Evolution of centrifugal distillation system with a thermoelectric heat pump for space missions. Part 1. Review of publications on centrifugal distillation in the period of 1990 – 2017. *J. Thermoelectricity*, 1, 5–15.
28. Perry Bruce A., Anderson Molly S. (2015). Improved dynamic modeling of the cascade distillation subsystem and analysis of factors affecting its performance. *45th International Conference on Environmental Systems 12-16 July 2015 (Bellevue, Washington). ICES-2015-216*.

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