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INFLUENCE OF THERMODYNAMIC CHARACTERISTICS OF A THERMOELECTRIC HEAT PUMP ON THE PERFORMANCE AND ENERGY CONSUMPTION OF A CENTRIFUGAL DISTILLER

The paper analyzes the operation of a thermoelectric heat pump in combination with a centrifugal distiller for the regeneration of wastewater from a human life system in the conditions of future long-term space missions. The time dependence of the specific energy consumption of the system at different capacities of the heat pump is shown, the influence of the temperature difference of the heat carriers on the efficiency of the heat pump is analyzed. Bibl. 24, Fig. 5, Tabl. 2.
Key words: thermoelectricity, heat pump, distiller.

Nomenclature

CMED – centrifugal distiller;
c_p – heat capacity, J/(kg·K)
G – liquid flow rate, l/h;
Q – heat flow, W;
G – flow rate, kg/h;
I – current strength, A;
N – power delivered to THP, W;
n – revolutions, rpm;
SPC – specific power consumption, W·h/kg;
THP – thermoelectric heat pump;
T, t – temperature, °C;
U – voltage, V;
η_{thp} – heat pump efficiency.

Subscripts

h – hot;
c – cold;
d – distiller;
avg – average;
in – inlet;
out – outlet;
thp – heat pump;
cd – motor

Introduction

One of the important requirements for water recovery systems from liquid waste in the conditions of long-term space expeditions to the Moon, Mars and work on the International Space Station (ISS) is the minimum energy consumption.

A team of engineers and scientists from Igor Sikorsky Kyiv Polytechnic Institute, the Institute of Thermoelectricity of the National Academy of Sciences of Ukraine and the commercial company "Termodistillation RV" developed in the period 2000 - 2003 a wastewater treatment system for operation in microgravity conditions. In publications [1-5], this system is called the cascade distillation system (CDS). The more correct name used here is Centrifugal Multistage Distillation (CMED) system. The system contains two main components - the centrifugal multi-stage distiller itself and the thermoelectric heat pump. Two methods are used to reduce energy costs: 1) the principle of multi-stage evaporation and liquid concentration and 2) energy recovery through the use of a thermoelectric heat pump.

In [6 – 15], the integral characteristics of CMED of 3-stage and 5-stage distillation are given. Shown are the results of testing when concentrating urine, atmospheric moisture condensate, sanitary water and their mixtures at fixed operating parameters of the system, heat pump power (≈ 400 W), rotor motor speed, etc.

This paper shows the results of testing a centrifugal multi-stage distiller with a thermoelectric heat pump, which was developed at the Institute of Thermoelectricity of the National Academy of Sciences of Ukraine and manufactured by company ALTEC. The calculated characteristics of the parameters affecting the efficiency η_{thp} are given.

Methods for researching the characteristics of a centrifugal distiller with a thermoelectric heat pump

Three identical five-stage centrifugal distillers have been developed and manufactured by Termodistillation RV. Altec has manufactured two thermoelectric heat pumps designed and manufactured by the Institute of Thermoelectricity of the National Academy of Sciences and the Ministry of Education and Science of Ukraine (ITE). These distillers, together with thermoelectric heat pumps, were first tested at Termodistillation RV and later transferred to Honeywell International Inc. The devices were then tested at the Honeywell test benches and at the NASA test bench at the Marshall Space Flight Center.

The test results of distillers and THP presented here have not been previously published.

Fig. 1 shows a schematic diagram of a test bench for three distillers and two heat pumps.

The main and auxiliary equipment of the bench are connected 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 distiller's motor 1 is turned on, which provides the specified speed of the distiller's rotor, and the necessary pressure is set in the apparatus by the vacuum pump 7, which corresponds to the required boiling point of the solution. From the tank 13 the distillate fills the cold circuit, which ensures the circulation of the distillate through the condenser of the distiller 1, the salt meter 9, the rotameter 14, the cold side of THP 2, the heat exchanger-cooler 3 and again the condenser of the distiller. The "hot" circuit is filled from tank 4 to the level set by the regulator valve 6. In the "hot" circuit, the solution circulates from the distiller evaporator 1 through the rotameter 14, the hot side of the THP 2 and again into the distiller evaporator 1. When electricity is supplied to 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 CMED 1 evaporator is partially evaporated, and the resulting steam is used as a heating distiller in the subsequent evaporation stage; the steam obtained in the last stage of the distiller is condensed in a contact condenser CMED 1. During the evaporation process, the concentration of dissolved substances in the hot circuit increases. Excess distillate from the "cold" circuit is automatically discharged into the distillate collector 5. The fresh solution is fed through valve 6. To ensure the stationary state of the distillation process, excess heat is removed by the heat exchanger-cooler 3 to the environment.

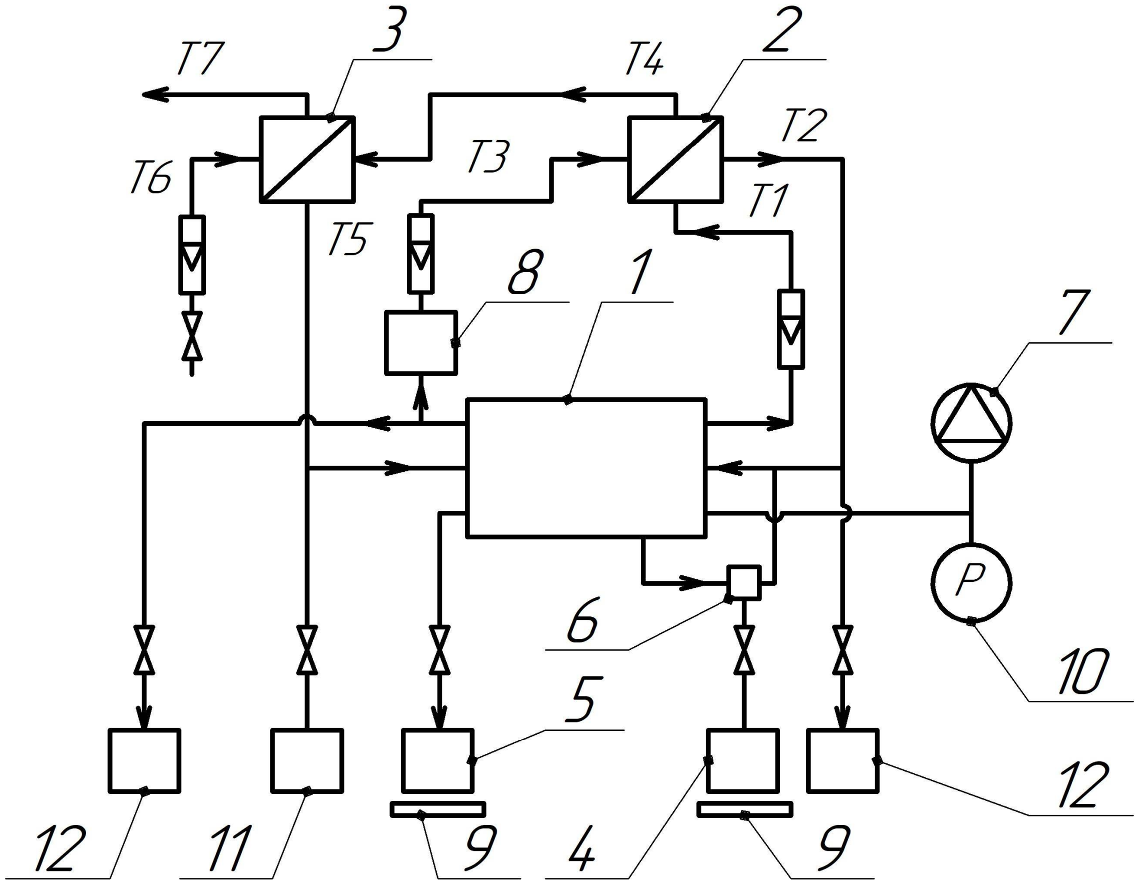

Fig. 1. Schematic of the experimental test bench
1 – centrifugal vacuum distiller; 2 – thermoelectric heat pump;
3 – heat exchanger-cooler; 4 – initial solution; 5 – distillate collector; 6 – system power regulator valve; 7 – vacuum pump; 8 – salt meter; 9 – salt meter; 10 – electronic scales;
11 –vacuum gauge; 13 – container with distillate for refilling the cold circuit;
14 – rotameters; 15 – stop valve; 16 – containers for emptying circuits.

After the end of the experiment, the power supply of THP 2 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 thermopile on the hot (t_1, t_2) and cold sides (t_3, t_4), after 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 by chromel-copel thermocouples, the measurement accuracy was ± 0.1 °C.

The pressure in the apparatus was measured with a vacuum gauge 11 with a measurement scale of

1 ... 0 bar (accuracy class 1.0) complete with a barometer.

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

The salinity in the "cold" circuit was measured by the Hanna salt meter (0...999 ppm).

The motor and heat pump drive powers were measured with a voltmeter and an ammeter, accuracy class 0.5. The revolutions were measured with a tachometer with an accuracy of ±1 rpm.

The test time (one test) was 60...120 min.

Results of the experimental study

At the Kiev Polytechnic Institute, studies (tests) of three CMEDs were carried out. Two heat pumps were used in the experiments. The rotation speed of the heat exchange surface varied from 900 to 1300 rpm, the power of the thermoelectric heat pump varied from 100 to 600 W. The working fluids were 1) distilled water; 2) NaCl solution with a concentration of 5 ... 30%; 3) urine with a concentration from 5 to 50%.

Experimental determination of η_{thp} depending on the input power and temperature difference

The heat flux generated at the outlet of the heat pump is defined as

$$Q_h = G_h c_p (t_2 - t_1), \tag{1}$$

where t_2 and t_1 are the outlet and inlet THP temperatures, respectively, °C.

η_{thp} – the efficiency is determined as $\eta_{thp} = Q_h / N_{thp}$

SPC – specific power consumption is defined as the total cost of input energy (power supplied to the distiller's motor and power supplied to the thermopile) spent on the production of one kilogram of distillate

$$SPC = \frac{\left(N_{cd} + N_{thp}\right)}{G_d}, \tag{2}$$

The average temperature difference in a thermoelectric heat pump ΔT_{avg} is defined as:

$$\Delta T_{avg} = \frac{\left(t_1 + t_2\right)}{2} - \frac{\left(t_3 + t_4\right)}{2}, \tag{3}$$

where t_1 is temperature at the inlet to THP heating zone, °C; t_2 temperature at the outlet of THP heating zone, °C; t_3 is temperature at the inlet to THP cooling zone, °C; t_4 is temperature at the outlet of THP cooling zone, °C.

The temperature difference at the inlet to the thermoelectric heat pump ΔT_{in} is defined as:

$$\Delta T_{in} = t_1 - t_3, \tag{4}$$

Table 1 provides an example of one test performed on a CMED with 5 steps at n = 1200 rpm on urine. All the initial values necessary to analyze the process are indicated: revolutions, power, time, temperature, costs, etc., and calculated values: supplied heat capacity, the degree of concentration of urine at the inlet and outlet of the device, the concentration in the residue, the efficiency of the heat pump.

Table 2 shows the main experimental parameters for each of the 32 tests performed in different periods of time on different devices. It should be noted that the main characteristics of the three manufactured centrifugal distillers, as well as two heat pumps, are identical (with the same parameters of the initial liquid, revolutions and power), as well as two heat pumps: performance, specific power consumption, distillate quality [16–19], which confirms the optimality of the developed CMED design in combination with THP.

Table 1

Results of testing five-stage centrifugal distiller with thermoelectric heat pump (rotation speed 1100 rpm, working fluid – urine)

Time	Motor			THP			Weight		Total dissolved solids	Flow rate		Performance	Specific power consumption SPC	Temperature			
	U	*I*	*N*	*U*	*I*	*N*	Initial liquid	Product (distillate)		Hot, G_h	Cold, G_c			Hot inlet to THP, t_1	Hot outlet from THP, t_2	Cold inlet to THP, t_3	Cold outlet from THP, t_4
min	V	A	W	V	A	W	gram	gram	mg/l	l/h	l/h	kg/h	W·h/kg	°C	°C	°C	°C
0	24.2	3.1	75	20.5	10.08	206.6	0	0	12	60	82	0	0	23.2	23.1	22.9	22.9
6	24.2	3.1	75	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	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**	**29.2**	**14**	**408.8**	**1122**	**1070**	**51**	**60**	**82**	**4.58**	**103.4**	**38.7**	**49.4**	**25.1**	**22.3**
24	24.2	3.1	75	30	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	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	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	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	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	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	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	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	33.1	15.56	515	5702	5508	90	63	83	5.02	117.5	40.9	53.1	24.9	22.0
78	24.2	3.1	75	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	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	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	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	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	8280	8205	96	71	83						

Fig.2 shows specific power consumption versus time for three five-stage distillers with a heat pump power of 400 W. In experiments on urine, the salt concentration increased over time up to 50%, and it should be noted that the efficiency of the system weakly depends on the concentration of the solution (see Fig. 2).

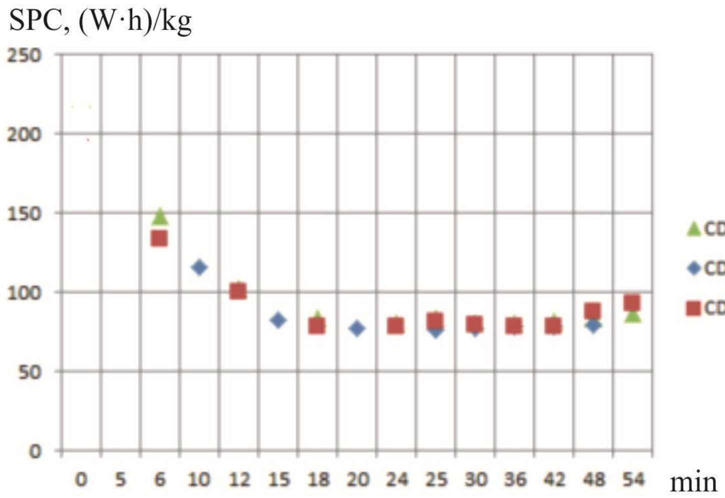

Fig. 2. Specific power consumption versus time for urine, N_{TTH} = 400 W, n = 1200 rpm.

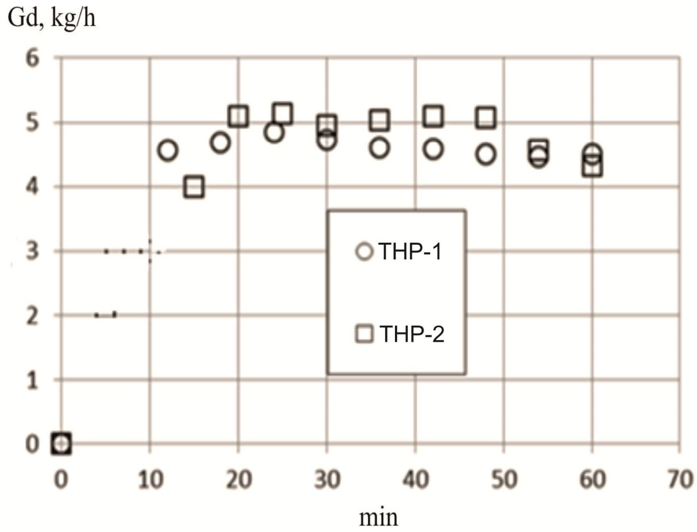

Fig. 3. System performance versus time for two samples of thermoelectric heat pumps, N_{thp} = 400 W, n = 1200 rpm.

The most important indicator of heat pump efficiency, η_{thp}, has high values in the investigated range of current strength (see Table 2). In general, the efficiency of a thermoelectric heat pump depends on the average temperature difference and the temperature difference at the inlet to the heat pump. In our works [20-21], this is analyzed and it is shown that the implementation of the process in the field of action of centrifugal forces significantly intensifies heat transfer, which, in turn, favorably affects the efficiency of the thermoelectric heat pump. As a result, the η_{thp} of the heat pump in our case varies from 2 to 5 depending on the current power.

NASA tested the TIMES distiller at the end of the 20th century. The system uses a polymer membrane that selectively allows water from the wastewater source to pass through. Power consumption is minimized by using solid state heat pumps. As a result, in experimental tests with non-concentrated urine, the maximum efficiency of a thermoelectric heat pump was approximately equal to only two [22-24].

Table 2

Main results of the experimental study for 32 selected tests

№	Liquid	Revolutions, n, rpm	Motor power, N_p, W	Heat pump power, N_{thp}, W	Current strength, I, A	Inlet temperature difference, $\Delta T_{in} = t_1 - t_3$	Average temperature difference, $\Delta T_{avg} = (t_1 + t_2)/2 - (t_3 + t_4)/2$	Delivered thermal power, Q, W	Heat pump efficiency, η_{thp}
1	Urine	1200	76	386	14.5	12.2	18.8	780	2.02
2	Water	1000	76	430	17.7	9	16.8	1000	2.33
3	Urine	1000	76	235	11	9	15.8	600	2.55
4	Urine	1000	77	240	11	9.7	15	614	2.56
5	Urine	1200	92	96.4	6.8	2.4	11.3	320	3.32
6	Urine	800	40	150	8.8	6.7	10	490	3.27
7	Urine	1000	71	150	8.8	8.8	12	459	3.06
8	Urine	1200	77	386	14	12	23.5	880	2.28
9	Urine	800	40	150	8.8	6.7	10	491	3.27
10	Urine	1000	70	150	8.8	8.8	12	459	3.06
11	Urine	1200	78	386	14	12	23.5	880	2.28
12	Water	1200	79	106	7.6	3.9	5.8	360	3.4
13	Water	1200	78	200	10.4	4.3	9.3	600	3.0
14	Water	1100	63	100	7.3	3.5	6.8	380	3.8
15	Water	1200	78	400	14.3	1.0	13.7	972	2.43
16	Water	1100	78	603	12.8	13.4	15.5	1110	1.84
17	Urine	900	59	150	8.7	5.3	10.5	495	3.3
18	Urine	1100	78	200	10.0	5.0	10.3	640	3.2
19	Urine	1300	100	63	2.0	1.5	3.8	351	5.4
20	Urine	1300	99	61	2.0	6.2	8.0	263	4.3
21	Urine	1300	98	100	7.0	3.2	7.3	330	3.3
22	Urine	1300	99	155	4.6	6.8	9.3	496	3.2
23	Water	1000	35.4	109	7.5	3.9	8.2	352	3.23
24	Water	1300	104	110	7.5	3.9	6.3	402	3.66
25	Water	900	35	200	10	5.1	10	492	2.46
26	Water	1300	98	200	10	4.5	10.2	528	2.64
27	Water	1100	78	606	17.6	10.5	16.5	196	1.94
28	Water	1000	51	101	7.3	3.5	6.8	379	3.75
29	Urine	1100	78	150	8.8	8.0	10.5	465	3.1
30	Urine	1100	77	150	8.8	5.7	9.2	540	3.6
31	Urine	1250	85	164	7.6	12	-	328	2.0
32	Urine	1100	79	165	13	13.5	-	396	2.4

The influence of the average temperature drop, the temperature difference at the THP inlet and the current strength on the efficiency of the ALTEC heat pump is shown in Fig. 4 and 5, respectively.

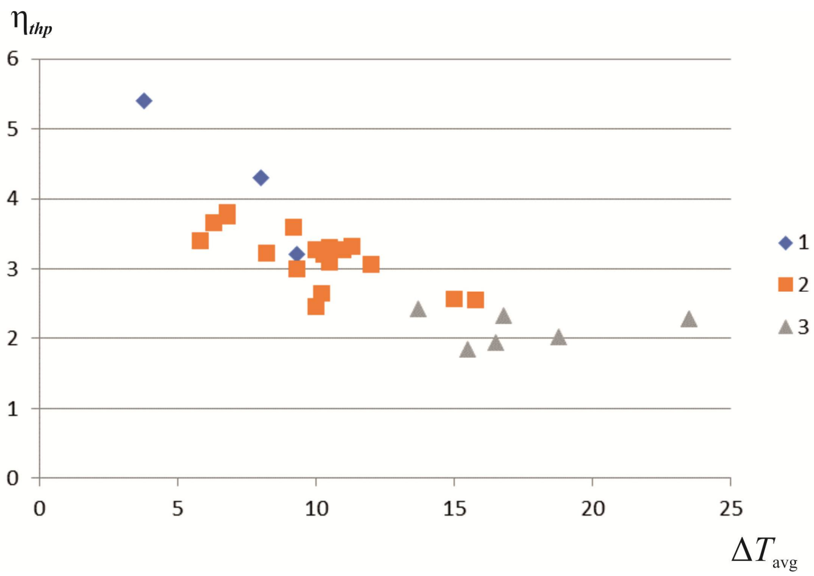

Fig. 4 Dependence of heat pump efficiency on the average temperature difference; current strength:◆ 1 – 2…4A; ■ 2– 7…10A; ▲ 3 13…17A;

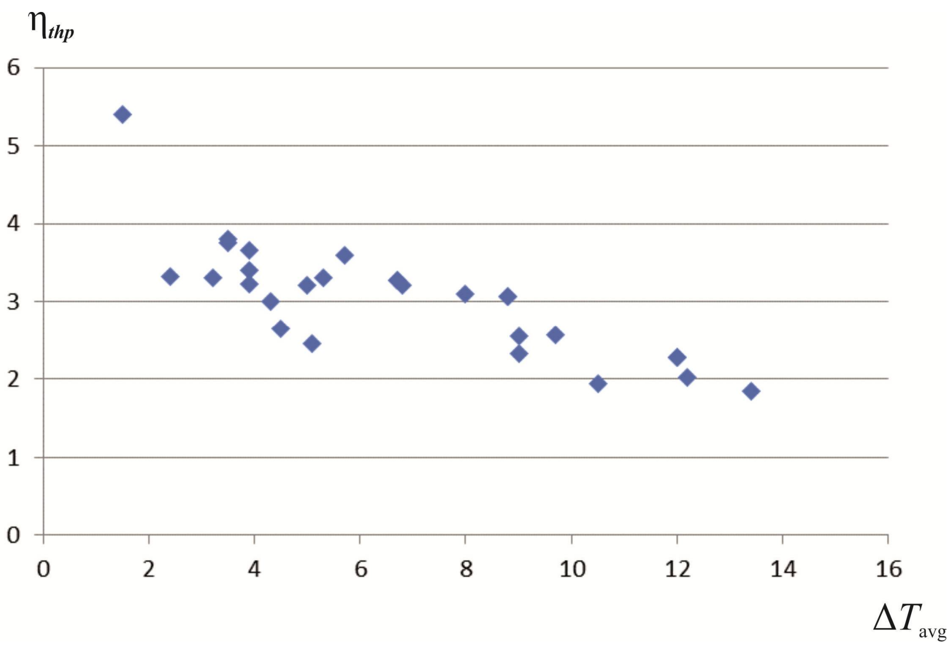

Fig. 5 Dependence of heat pump efficiency on the temperature difference at the inlet to heat pump.

Conclusions

The conducted experimental studies have shown that in the developed system of a centrifugal distiller with a thermoelectric heat pump, it is possible to achieve high performance indicators of the thermopile, the heat pump efficiency η_{thp} is in the range of 3…5. This can be achieved due to very intense heat transfer processes in the field of action of centrifugal forces, which makes it possible to maintain a minimum average temperature difference of the working fluids in a thermoelectric heat pump. The obtained data will be used to create a mathematical model of a water distillation system (centrifugal distiller + thermoelectric heat pump) and to design a water regeneration system for a given capacity with a predicted specific power consumption.

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References

1. Sargusingh M. J., Callahan M. R. (2015). Cascade distillation system design for safety and mission assurance. *45th International Conference on Environmental Systems ICES-2015-151* (12-16 July 2015, Bellevue, Washington).
2. 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. *34st International Conference on Environmental Systems* (Orlando, July 2003).
3. 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).
4. 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).

5. Callahan M., Patel V., Pickering K.D. (2010). Cascade distillation subsystem development: early results from the exploration life support distillation technology comparison test. *40th International Conference on Environmental Systems* (11 July 2010 - 15 July 2010, Barcelona, Spain).
6. 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).
7. 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 *The 24th International Society Conference on Environmental Systems* (June, 1994).
8. 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 *The 25th International Conference on Environmental Systems* (San Diego, July 1995).
9. 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. *The 27th International Conference on Environmental Systems* (Nevada, July 1997).
10. 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. *The 29th International Conference on Environmental Systems* (Denver, July 1999).
11. 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. *The 29th International Conference on Environmental Systems* (Denver, July 1999).
12. 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. *The 30th International Conference on Environmental Systems* (Toulouse, France, 10-13 July 2000).
13. Rifert V., Usenko V., Zolotukhin I., MacKnight A. and Lubman A. (2001). Design optimisation of cascade rotary distiller with the heat pump for water reclamation from urine, SAE Paper 2001-01-2248. *The 31st International Conference on Environmental Systems* (Orlando, July 2001).
14. 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.
15. Rifert V.G., Barabash P.A., Usenko V., Solomakha A.S., Anatychuk L.I., Prybyla A.V. (2017). Improvement the cascade distillation system for long-term space flights. *The 68th International Astronautical Congress (IAC)* (Adelaide, Australia, 25-29 September 2017). IAC-17-A1.IP.25.
16. Rifert Vladimir G., Anatychuk Lukyan I., Solomakha Andrii S., Barabash Petr A., Usenko Vladimir, Prybyla A.V., Naymark Milena, Petrenko Valerii (2019). Upgrade the centrifugal multiple-effect distiller for deep space missions. *The 70th International Astronautical Congress (IAC)* (Washington D.C., United States, 21-25 October 2019). IAC-19-A1, IP, 11x54316.
17. 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 3. Analysis of local and integral characteristics of centrifugal distillation system with thermoelectric heat pump. *J. Thermoelectricity*, 3, 5 – 19.
18. 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). Comparative analysis of thermal distillation methods with heat pumps for long space flights. *J.Thermoelectricity*, 4, 5 – 17.
19. Solomakha A.S., Anatychuk L.I., Rifert V.G., Barabash P.A., Usenko V., Petrenko V. (2020). Thermal distillation system for deep space missions: rationale for the choice. *The 71st International*

Astronautical Congress (IAC) (The CyberSpace Edition 12-14 October 2020). IAC-20-A1,VP,15,x61344. 7 pages.
20. Rifert V.G., Barabash P.A., Solomakha A.S., Usenko V., Sereda V.V., Petrenko V.G. (2018). Hydrodynamics and heat transfer in centrifugal film evaporator. *Bulgarian Chemical Communications*, Vol.50, Special Issue K., 49-57.
21. Rifert V.G., Solomakha A.S., Barabash P.A., Usenko V., Sereda V.V. (2020). Justification of the method for calculating heat transfer in film evaporators with a rotating surface. *Bulgarian Chemical Communications*, Vol.52, Special Issue F,95-102. DOI: 10.34049/bcc.52.F.0016
22. Thibaud-Erkey, C., Fort, J., and Edeen, M. (2000). A new membrane for the thermoelectric integrated membrane evaporative subsystem (TIMES). *SAE Technical Paper* 2000-01-2385 1999-01-1990
23. Dehner G.F. TIMES Regenerator Redesign Description Timothy D. Scull Hamilton Standard Space Systems International, Inc. Addendum development of a preprototype times wastewater recovery subsystem. Prepared under contract no. nas 9-15471, 1984.
24. A new membrane for the thermoelectric integrated membrane evaporative subsystem (TIMES) Catherine Thibaud-Erkey and James H. Fort Hamilton Sundstrand Space Systems International Marybeth A. Edeen NASA-Johnson Space Center Water Recovery Technology, *SAE Technical Paper* 820849, 1982. 2000-01-2385

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ВПЛИВ ТЕРМОДИНАМІЧНИХ ХАРАКТЕРИСТИК ТЕРМОЕЛЕКТРИЧНОГО ТЕПЛОВОГО НАСОСА НА ПРОДУКТИВНІСТЬ ТА ВИТРАТИ ЕНЕРГІЇ ВІДЦЕНТРОВОГО ДИСТИЛЯТОРА

У статті проведено аналіз роботи термоелектричного теплового насоса у комплексі з відцентровим дистилятором для регенерації стічних вод системи життєдіяльності людини в умовах майбутніх космічних місій. Показано залежність питомого споживання енергії системи від часу за різних потужностей теплового насоса, проаналізовано вплив різниці температур теплоносіїв на ефективність роботи теплового насоса. Бібл. 24, рис. 5, табл. 2.
Ключові слова: кабіна: термоелектрика, тепловий насос, дистилятор.

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ВЛИЯНИЕ ТЕРМОДИНАМИЧЕСКИХ ХАРАКТЕРИСТИК ТЕРМОЭЛЕКТРИЧЕСКОГО НАСОСА НА ПРОИЗВОДИТЕЛЬНОСТЬ И РАСХОД ЭНЕРГИИ ЦЕНТРОБЕЖНОГО ДИСТИЛЛЯТОРА

В статье проведен анализ работы термоэлектрического теплового насоса в комплексе с центробежным дистиллятором для регенерации сточных вод системы жизнедеятельности человека в условиях будущих длительных космических миссий. Показана зависимость удельного потребления энергии системы от времени при разных мощностях теплового насоса, проанализировано влияние разности температур теплоносителей на эффективность работы теплового насоса. Библ. 24, рис. 5, табл. 2.
Ключевые слова: термоэлектрика, тепловой насос, дистиллятор.

References

1. Sargusingh M. J., Callahan M. R. (2015). Cascade distillation system design for safety and mission assurance. *45th International Conference on Environmental Systems ICES-2015-151* (12-16 July 2015, Bellevue, Washington).
2. 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. *34st International Conference on Environmental Systems* (Orlando, July 2003).
3. 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).
4. 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).
5. Callahan M., Patel V., Pickering K.D. (2010). Cascade distillation subsystem development: early results from the exploration life support distillation technology comparison test. *40th International Conference on Environmental Systems* (11 July 2010 - 15 July 2010, Barcelona, Spain).
6. 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).
7. 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 *The 24th International Society Conference on Environmental Systems* (June, 1994).
8. 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 *The 25th International Conference on Environmental Systems* (San Diego, July 1995).
9. 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. *The 27th International Conference on Environmental Systems* (Nevada, July 1997).
10. 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. *The 29th International Conference on Environmental Systems* (Denver, July 1999).
11. 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. *The 29th International Conference on Environmental Systems* (Denver, July 1999).
12. 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. *The 30th International Conference on Environmental Systems* (Toulouse, France, 10-13 July 2000).
13. Rifert V., Usenko V., Zolotukhin I., MacKnight A. and Lubman A. (2001). Design optimisation of cascade rotary distiller with the heat pump for water reclamation from urine, SAE Paper 2001-01-2248. *The 31st International Conference on Environmental Systems* (Orlando, July 2001).
14. 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.
15. Rifert V.G., Barabash P.A., Usenko V., Solomakha A.S., Anatychuk L.I., Prybyla A.V. (2017). Improvement the cascade distillation system for long-term space flights. *The 68th International Astronautical Congress (IAC)* (Adelaide, Australia, 25-29 September 2017). IAC-17-A1.IP.25.
16. Rifert Vladimir G., Anatychuk Lukyan I., Solomakha Andrii S., Barabash Petr A., Usenko Vladimir, Prybyla A.V., Naymark Milena, Petrenko Valerii (2019). Upgrade the centrifugal multiple-effect distiller for deep space missions. *The 70th International Astronautical Congress (IAC)* (Washington D.C., United States, 21-25 October 2019). IAC-19-A1, IP, 11x54316.
17. 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 3. Analysis of local and integral characteristics of centrifugal distillation system with thermoelectric heat pump. *J. Thermoelectricity*, 3, 5 – 19.
18. 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). Comparative analysis of thermal distillation methods with heat pumps for long space flights. *J.Thermoelectricity*, 4, 5 – 17.
19. Solomakha A.S., Anatychuk L.I., Rifert V.G., Barabash P.A., Usenko V., Petrenko V. (2020). Thermal distillation system for deep space missions: rationale for the choice. *The 71st International Astronautical Congress (IAC)* (The CyberSpace Edition 12-14 October 2020). IAC-20-A1,VP,15,x61344. 7 pages.
20. Rifert V.G., Barabash P.A., Solomakha A.S., Usenko V., Sereda V.V., Petrenko V.G. (2018). Hydrodynamics and heat transfer in centrifugal film evaporator. *Bulgarian Chemical Communications*, Vol.50, Special Issue K., 49-57.

21. Rifert V.G., Solomakha A.S., Barabash P.A., Usenko V., Sereda V.V. (2020). Justification of the method for calculating heat transfer in film evaporators with a rotating surface. *Bulgarian Chemical Communications*, Vol.52, Special Issue F,95-102. DOI: 10.34049/bcc.52.F.0016
22. Thibaud-Erkey, C., Fort, J., and Edeen, M. (2000). A new membrane for the thermoelectric integrated membrane evaporative subsystem (TIMES). *SAE Technical Paper* 2000-01-2385 1999-01-1990
23. Dehner G.F. TIMES Regenerator Redesign Description Timothy D. Scull Hamilton Standard Space Systems International, Inc. Addendum development of a preprototype times wastewater recovery subsystem. Prepared under contract no. nas 9-15471, 1984.
24. A new membrane for the thermoelectric integrated membrane evaporative subsystem (TIMES) Catherine Thibaud-Erkey and James H. Fort Hamilton Sundstrand Space Systems International Marybeth A. Edeen NASA-Johnson Space Center Water Recovery Technology, *SAE Technical Paper* 820849, 1982. 2000-01-2385

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