ASPECTS OF MINIATURE AXIAL GROOVE HEAT PIPES DEVELOPMENT

V. Barantsevich, K. Goncharov
Heat Pipe Center of Lavochkin Assotiation
24 Leningradskaya str., Khimky, Moscow region, 141400, Russia
Tel/fax (7-495)-5736374, E-mail: HEATPIPE@BERC.RSSI.RU

Abstract

This paper is devoted to the development of miniature axial grooved heat pipes (mini AGHP) of 5mm and less providing within operating temperature range from minus 40 to plus 80°C heat transfer capability of 10–12 W·m with heat supply and heat rejection zones (0,01-0,03) m and (0,05-0,1) m respectively. After comparing the results of calculations with the results of various dimension-type AGHP experimental researches we have a reason to confirm that it is impossible to obtain the required parameters on base of the traditional AGHP. One of the solutions can be application of a combined capillary structure by introducing into the heat supply zone an insert made from the sintered aluminum fibers that will allow twice increase of the heat flow limiting value.

INTRODUCTION

Axial Grooved Heat Pipes (AGHP) are widely applied for thermal control systems in various technical fields. They are mostly used in space equipment because of the minimum expenses spent for obtaining by method of extrusion a great variety of forms for cross-section of the profiles used for heat pipes production. The good reproducibility of the profiles geometrical parameters, good compatibility of aluminum alloys used for the profiles with the most accepted working fluids (ammonia, propylene, ethane and etc.) that allows to meet the requirements of the heat pipes lifetime are the reasons for AGHP wide application too.

A whole row of aluminum profiles with structural height from 6 to 20 mm that allows to provide AGHP with heat transfer capability from 40 to 600 W·m has been developed and is being widely applied in Lavochkin Association.

Recently it has aroused an interest in development of AGHP with diameter of 5 mm and less apparently for the needs of the modern electronics. The tender for such AGHP invited by the European Space Agency (ESA) at the end of 2007 provides evidence of it.

We have estimated possibility of AGHP development with heat transfer capability of 8 – 10 W·m within the operating temperature range from minus 40 to plus 80 °C, up to 0,5 m long and with length of heat supply and heat rejection zones 0,01–0,03 m and 0,03–0,1 m respectively.

DESIGN OF MINI AGHP AND CALCULATION RESULTS

Preliminary analysis showed technical feasibility of AGHP design with structural depth of 4–5 mm (Fig. 1) which geometrical parameters are presented in the Table 1.

Table 1. Geometrical parameters of the profile for AGHP

Heat Pipe Model	A, mm	B, mm	t, mm	D, mm	d_v, mm	d_1, mm	δ, mm	Number of grooves	Profile weight, g/m
Mini AGHP-4	10	4	0.6	4.0	2.2	3.3	0.35	11	46
Mini AGHP-5	10	5	0.6	5.0	2.8	4.2	0.4	13	53

It is known that there are some limits of heat pipes efficiency. For low-temperature AGHP the main limiting factors are hydrodynamic limit and boiling limit. Calculation of the ultimate heat flows for AGHP with geometrical parameters shown in the table 1 was performed by using appropriate relations from the monograph [1] and presented in Fig. 2 as a plot of AGHP heat transfer capability versus operating temperature.

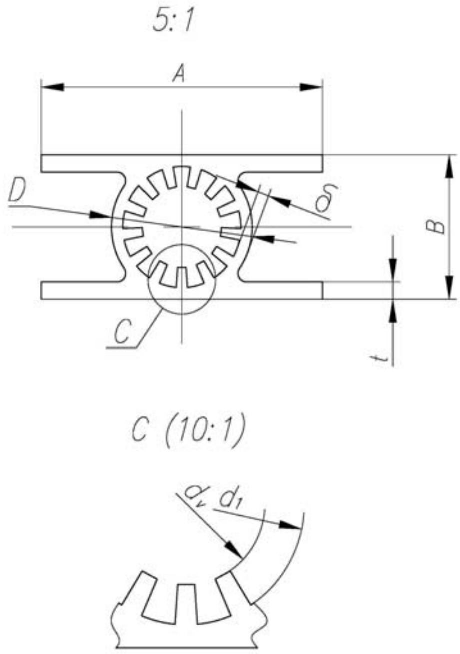

Fig. 1. Profile for AGHP

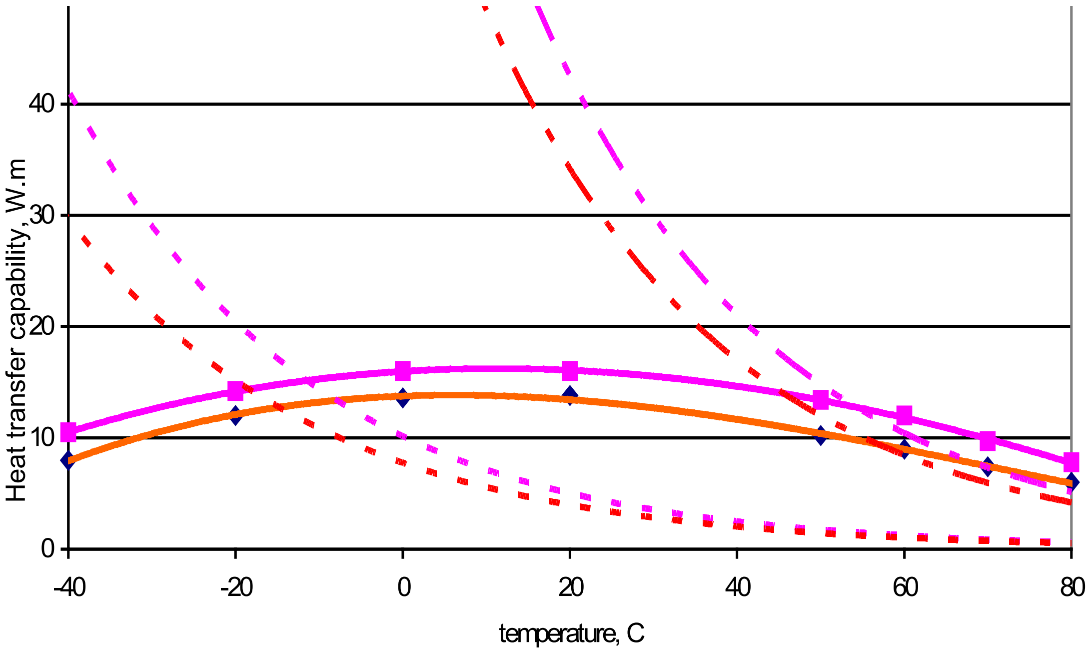

Fig. 2. Operating temperature effect on heat transfer capability of mini AGHP:
hydrodynamic limit - AGHP-5; - AGHP-4;
boiling limit - AGHP-5; - AGHP-4 ($r_n = 2{,}54 \cdot 10^{-7}$ m)
boiling limit - AGHP-5; - AGHP-4 ($r_n = 2{,}54 \cdot 10^{-8}$ m)

The data taken for calculation are as follows:
- AGHP length – 0.5 m; length of the heat supply zone – 0.03 m;
- length of the heat rejection zone – 0.05 m.

It is clear from the formula for calculation of the boiling limit

$$Q_b = \frac{2\pi L_{ev} k_{ef} T_v}{\lambda \rho_v \ln\left(\frac{r_1}{r_v}\right)} \left(\frac{2\sigma}{r_n}\right) \tag{1}$$

that it includes radius of the vapor bubble nucleus (r_n) which value is in accordance with B. Marcus investigations from $2.54 \cdot 10^{-8}$ to $2.54 \cdot 10^{-7}$ m [2] in dependence on the working fluid purity. As there is not enough data regarding its quantity, the formula (1) gives the approximate value of the boiling limit. We have compared the results of experimental researches on determination of the heat flow limiting values for the number of various dimension-type AGHPs (AGHP-6, AGHP-12,5 and AGHP-15x15) with the calculation results of the boiling limit performed by the formula (1) within the specified range of vapor first stage radius value (Fig. 3–5).

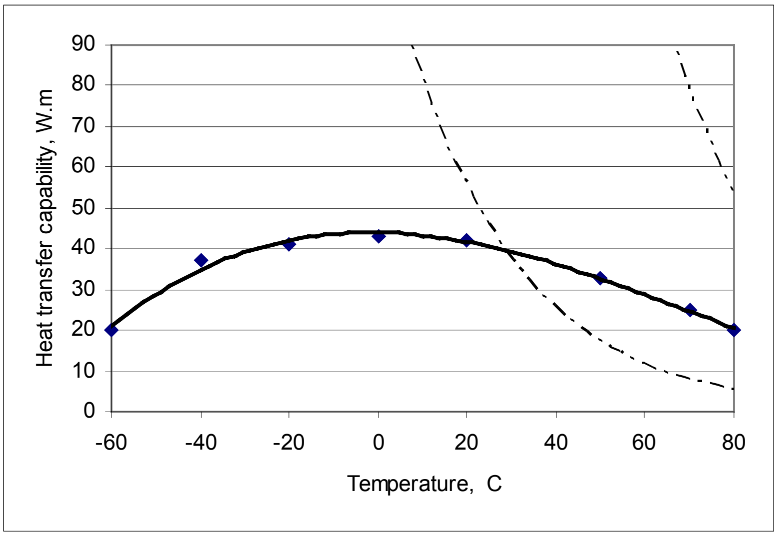

Fig. 3. Limiting values of AGHP-6 heat transfer capability:
— experiment (L_{AGHP} = 1,2 m, L_{ev} = 0,2 m, L_{cond} = 0,2 m);
–·–·–·–·– – boiling limit calculation (formula 1) $r_n = 2{,}54 \cdot 10^{-7}$m;
–··–··–··– – boiling limit calculation (formula 1) $r_n = 2{,}54 \cdot 10^{-8}$m

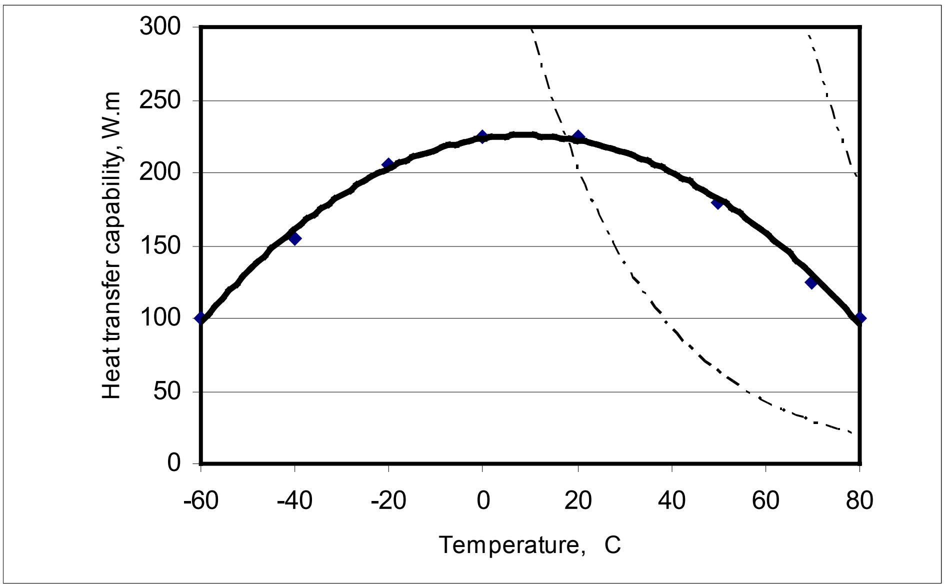

Fig. 4. Limiting values of the AGHP-12,5 heat transfer capability:
— - experiment (L_{ATT} = 2 m, L_{ev} = 0,35 m, L_{cond} = 0,3 m);
–·–·–·–·- - boiling limit calculation (formula 1) $r_n = 2{,}54 \cdot 10^{-7}$m;
–··–··–·- - boiling limit calculation (formula 1) $r_n = 2{,}54 \cdot 10^{-8}$m

Analysis of the data presented in Fig. 3–5 shows that the real value of the vapor bubble nucleus is close to the lower limit of the value recommended by Marcus. Rather high purity of the original working fluid (99,999 %) favors it. Analysis of the results presented in Fig. 2 shows that even at the minimum value of the vapor bubble nucleus and specified length of the heat supply zone the boiling limit becomes determinative at the operating temperature 50 °C and more. Reduction of the heat supply zone length will make this limit shift to the area of the lower temperatures. Therefore, it is scarcely realizable for traditional AGHP to have the required heat transfer capability at the heat supply zone length less than 0,03 m and heat flow density in the heat supply zone up to 7 W/cm^2.

In our opinion it is possible to increase efficiency of mini AGHP by applying the combined capillary structure by means of introducing into the evaporating zone an insert from the sintered aluminum fibers instead of the longitudinal grooves. At first the aluminum fibers sintering was performed by the paper authors [3] and successfully realized in number of the combined heat pipes used in thermal control systems of space monitoring equipment. Seven years monitoring of the spacecraft “METEOR-PRIRODA” No. 3–1 operation showed reliability and efficiency of this solution [4].

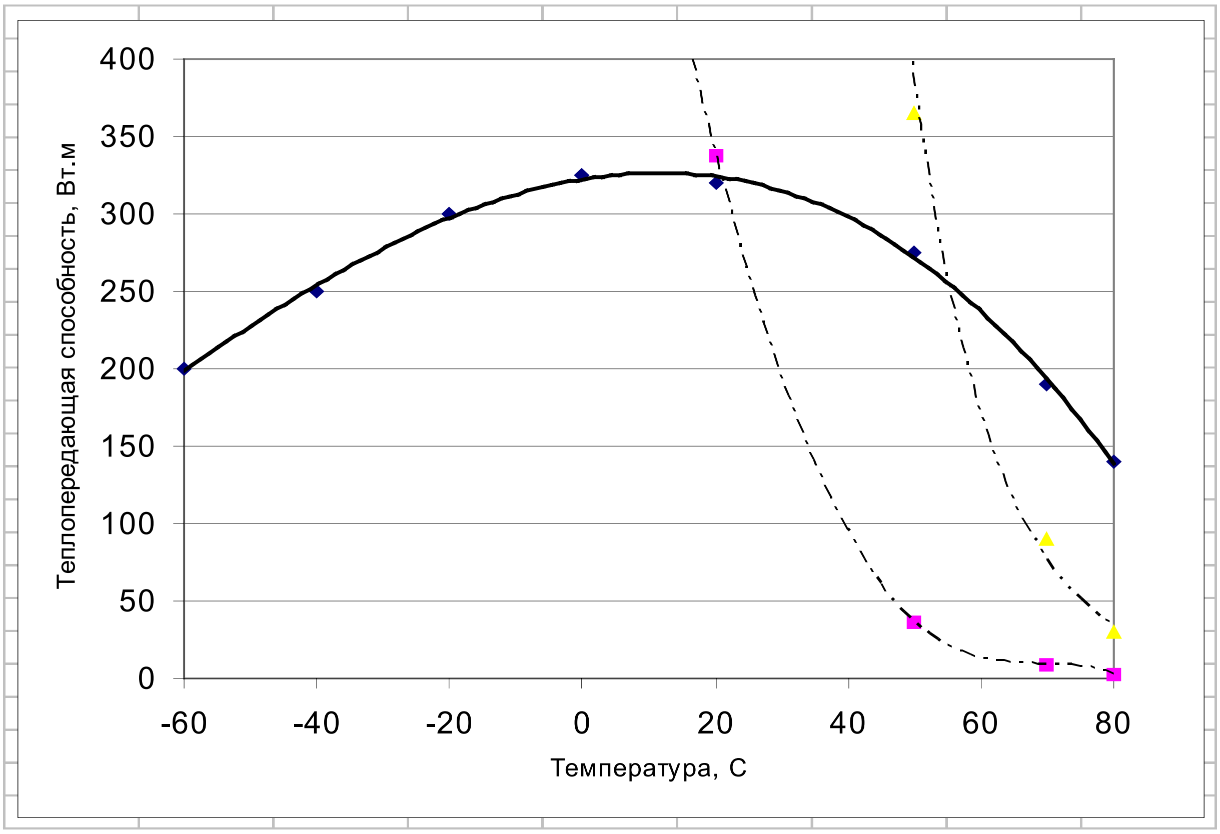

Fig. 5. Limiting values of the AGHP-15x15 heat transfer capability:
——— - experiment (L_{AGHP} = 2 m, L_{ev} = 0,35 m, L_{cond} = 0,3 m);
-·-·-·- - boiling limit (formula 1) r_n = 2,54· 10^{-7} m;
--·--·-- - boiling limit (formula 1) r_n =2,54· 10^{-8} m

The experiments with heat pipes showed that introduction of the porous insert into the AGHP evaporation zone allows both to increase its limiting power and increase almost twice as much the limiting value of the heat flow density in the heat supply zone. These investigations results were published in the paper [5]. It was determined that application of the combined capillary structures was efficient when the length of the heat supply zone was not more than 0,1 of the AGHP total length.

The production stages of the heat pipe with the porous insert are as follows:

- remove the ribs on one end of the profile at length corresponding to the length of the heat supply zone (grooves edges must be free from cuts);

- sinter the porous insert from aluminum fibers with diameter of 30-50 mkm (the insert thickness corresponds to the height of the ribs in the heat pipe profile, porosity is 60-75 %);
- install the insert into the body of the semi-manufactured heat pipe, joining reliably the porous insert with the edges of AGHP ribs.

It is also possible to manufacture the heat supply zone with the sintered capillary structure as a separate unit to be welded afterwards to the basic part of AGHP. Due to considerable porosity of the sintered insert, weld penetration into the structure does not occur.

CONCLUSIONS

Development of mini AGHP with structural depth of 5 mm and less in its traditional design with parameters suitable for real application is impossible because of the high density of heat flow in evaporator.

In order to increase mini AGHP characteristics we need to decrease the heat flow density by increasing the evaporator length and intensify heat and mass exchange in evaporation zone, for example, by introducing porous inserts on base of the sintered aluminum fibers.

NOMENCLATURE

k_{ef} – efficient heat conductivity of the wick saturated with liquid;
L_{ev} – length of the heat supply zone;
Q_b – boiling limit;
r_1, r_v – radius of the groove bottom and vapor line;
r_n – radius of the vapor bubble nucleus;
T_v – vapor temperature;
λ – heat of working fluid vaporization;
ρ_v – vapor density;
σ – coefficient of surface tesion.

References

1. Chi S. W. Heat Pipe. Theory and Practice, Washington-London: Hemisphere Publishing Corporation, 1976.
2. Marcus B. D. Theory and Design of Variable Conductance Heat Pipes, NASA CR-2018, April, 1972.
3. Barantsevich V. L., Veretennikov B. N., Opryshko S. I., Solodov Y. P, Yatsenko Ye.S. Sintering of silicon doped aluminum fibers // *Powder metallurgy*, Kiev, 1981. No. 221. Pp. 27–29.
4. Barantsevich V.L., Opryshko S.I. Studies of Heat Pipes with combined capillary structure // *Prepr. Intern. Conf. on Heat transfer in Energy Conservation. Shenyang, China, October 6–9*, 1988. Pp. 247–250.
5. Barantsevich V. L., Ovchinnikov B.N. The Heat transfer characteristics improvement of the axial groove heat pipes // *Preprint of 8th Intern. Heat Pipes conference, Beijing, China, 14-18 Sept.*, 1992. B-p17-1-Bp17-5.