EFFECT OF WORKING FLUID SELECTION ON THERMAL PERFORMANCE OF HEAT EXCHANGER FILLED BY THE POROUS MATERIAL

Paweł Szymanski, PhD

Faculty of Ocean Engineering and Ship Technology,
Gdansk University of Technology
ul. Narutowicza 11/12, 90-950 Gdańsk, Poland
tel.: +48 58 3472430, fax: +48 58 3472430
e-mail: pawszym1@pg.gda.pl

Abstract

Thermal management of electronics semiconductor technologies that are located i.e. in a novel marine power plants or computer server rooms become very important issue for designers of such systems. Motivation and need for research in development of novel cooling strategies for modern electronics is of paramount importance.
Heat exchangers filled by the porous material are a novel research topic in current heat pipe science. The design of such heat exchangers is rather complex with many things to consider. In this paper the focused is the get knowledge about who to select the working fluid to be used.

Keywords: *Capillary Pumped Loop, Loop Heat Pipes*

Introduction

Many factors decide about the correct choice of the fluid working in the system with heat exchanger filled by the porous material. Figure 1 presents an installation with heat exchanger filled by the capillary material. The installation is based on Loop Heat Pipe, that is two phase heat transfer device that uses capillary action to remove heat from a source and passively move it to a condenser or radiator.

Important factors taken into account when selecting fluid are: the temperature range in which the heat exchanger will work, thermal conductivity, toxicity and lack of chemical reaction material of the heat exchanger components. There are many combinations of working fluids and their use in traditional heat pipes [1-4].
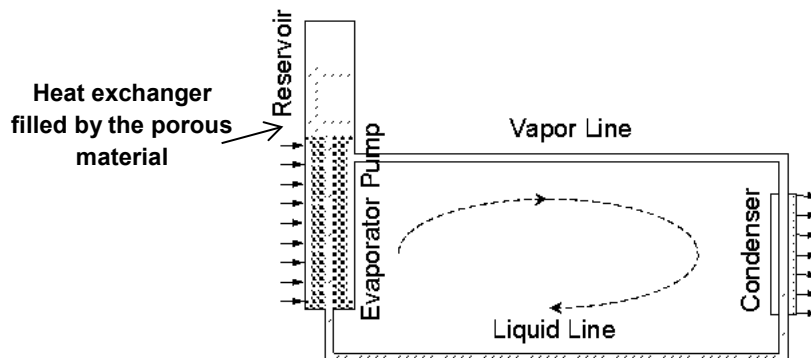

Fig 1. Installation with heat exchanger filled by the porous material

The basic classification of the working fluids is the division due to the temperature range in which heat exchanger will work, *i.e.* cryogenic fluids (helium, neon, oxygen, hydrogen), fluids for medium temperatures (methanol, ethanol, ammonia, acetone, water), or high-temperature liquid metals (potassium, lithium, potassium). Table 1 shows the typical operating temperature ranges for different working fluids.

Tab 1. Operating temperature range for different working fluids used in heat pipes. [1]

Working Fluid	Melting point at atmospheric pressure [°C]	Boiling point at atmospheric pressure [°C]	Operating temperature range [°C]
Helium	-272,15	-268,95	-271,15 ÷ -269,15
Hydrogen	-259,35	-252,75	-259,15 ÷ -242,15
Neon	-248,75	-246,05	-246,15 ÷ -236,15
Nitrogen	-210,05	-195,75	-203,15 ÷ -170,15
Argon	-189,25	-185,85	-189,15 ÷ -157,15
Oxygen	-218,45	-182,95	-200,15 ÷ -154,15
Krypton	-157,35	-153,45	-157,15 ÷ -113,15
Ammonia	-77,65	-33,25	-60,15 ÷ 99,85
Pentane	-130,05	36,05	-20,15 ÷ 119,85
Freon 113	-36,65	47,65	-10,15 ÷ 99,85
Acetone	-93,15	56,25	-0,15 ÷ 119,85
Water	-0,05	99,95	29,85 ÷ 199,85
Mercury	-38,95	356,95	249,85 ÷ 649,85
Sulfur	112,75	444,65	256,85 ÷ 673,85
Sodium	97,85	877,85	599,85 ÷ 1199,85
Lithium	180,55	1341,85	999,85 ÷ 1799,85
Silver	960,85	2111,85	1799,85 ÷ 2299,85

For optimum operation of heat exchanger, the working fluid must have the following properties: a large latent heat of vaporization necessary for efficient heat transfer, a high thermal conductivity to minimize pressure drop along the wick, a large surface tension to maximize the possibility of capillary transport and low viscosity to minimize the pressure losses in the fluid transport lines [5].

Calculations

Initially analyzed 15 different working fluids which can be used in the system to produce a maximal capillary pressure difference. These were acetone, ethanol, ammonia, R123, toluene, water, R365mfc, R141b, R245ca, R134a, R245fa, R236ea, perfluorpentane C5F12, R227ea, RC318. It was assumed that working fluids should evaporate at a temperature up to 230°C, and the condensation process should takes place at a temperature of 10°C.

The effect of surface tension on the temperature distribution of selected working fluids are shown in Figure 1, the achievable pressure drop of the capillary shown in Figures 2a and 2b.
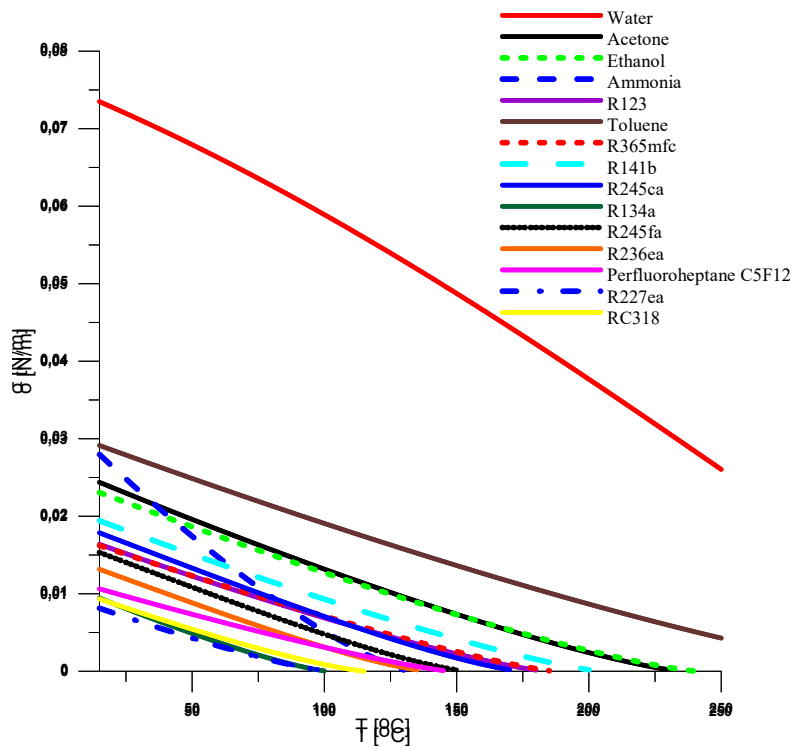
Fig. 1. The effect of surface tension on temperature for different working fluids.
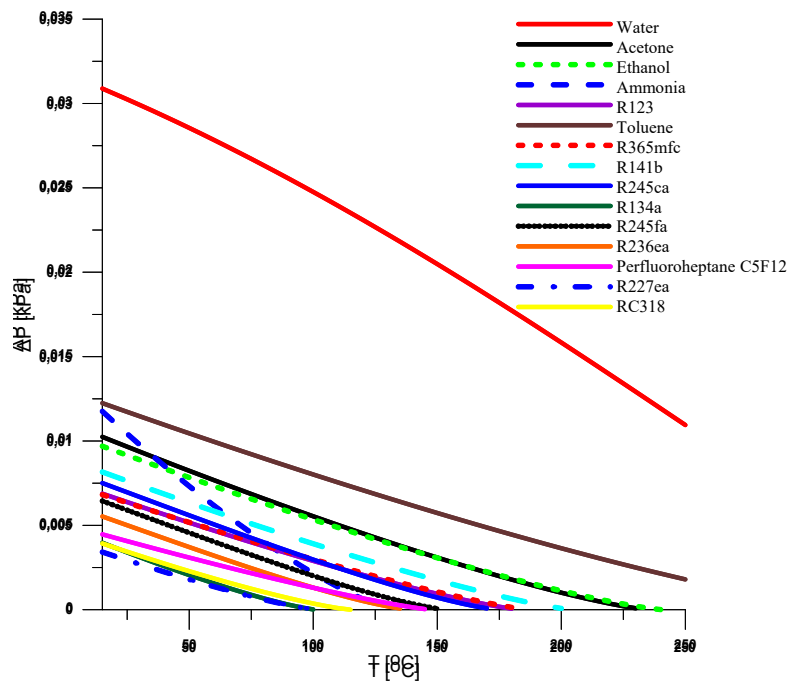

Fig. 2a. Effect of capillary pressure rise pressure on the temperature for different working fluids (for the assumed contact angle of liquid equal to 45°).
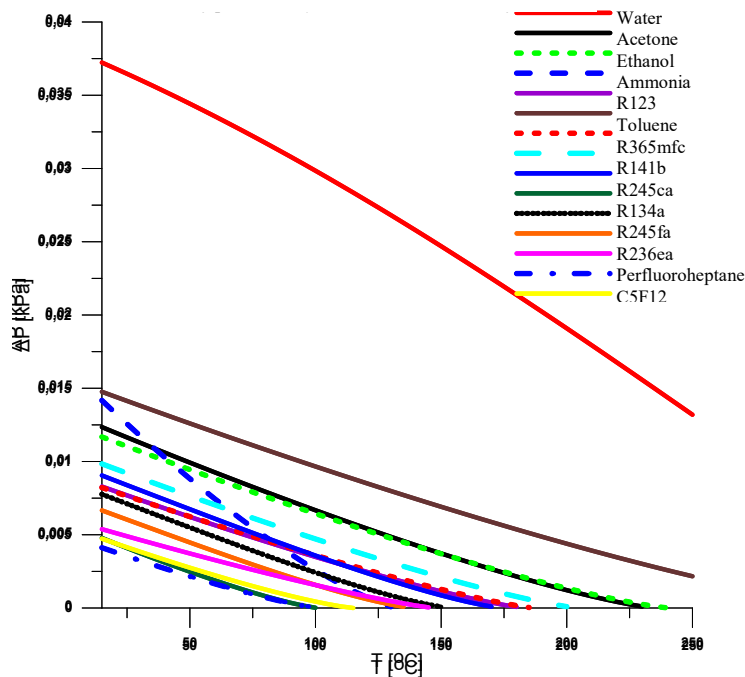
Fig. 2b. Effect of capillary pressure rise pressure on the temperature for different working fluids (for the assumed contact angle of liquid equal to 70°).

For the calculation of the maximum increase of the pressure drop possible create by the wick, used the formula:

$$\Delta P_{capillary,\max} = \frac{2\sigma \cos\theta}{R_p} \tag{1}$$

in which a contact angle θ assumed a value of 45° and 70° for all selected working fluids, and the effective radius of a single season of porous material adopted $R_p = 2.5$ microns, or as much as will be examined pore size in the porous material of the evaporator.

Results and conclusion

Analysis of the data shows that not all working fluids are suitable for use in the system, due to the expected operating temperature. Some fluids, such as ammonia, R123, R365mfc, R245ca, R134a, R245fa, R236ea, perfluoropentane C5F12, R227ea, RC318 are suitable for use, but at lower temperatures *i.e.* 150 ÷ 180°C. The greatest potential for producing a differential pressure capillary is offered by water, toluene, acetone and ethanol. As can be seen from the above graph of surface tension and the maximum capillary pressure rise for acetone and ethanol are very similar, so that between these two factors selected only one (acetone).

In the case of toluene, due to its highly toxic to man (toluene vapors are very harmful for the respiratory system, blood, nervous and immune systems), and the associated danger in use in the laboratory, it was decided not to study this factor system.

With the above factors, the highest surface tension value reaches the water and can be successfully used in the intended operating temperatures of the installation so that, in addition to acetone, it was decided to test the position of the experimental.

As stated above, after the preliminary examination of these fluids, it was decided that the water and acetone are the best fluids capable of being used in the test system. These fluids are easily accessible, chemically inert to the structural position of experimental and technical parameters are in accordance with the parameters of the system. Table 2a and 2b shows a comparison of technical parameters of technical acetone and water.

Tab 2a Comparison of basic technical parameters of water and acetone.

Working Fluid	Critical pressure	Critical Temperture	Molar mass	triple point temperature	Normal Boiling Point
	[kPa]	[ºC]	[kg/kmol]	[ºC]	[ºC]
Water	22064	373,95	18,015	0,01	99,974
Acetone	4700	234,95	58,079	-94,65	56,07

Tab 2b Comparison of physical parameters of water and acetone according to the temperature.

Working Fluid	Density Liquid	Density Vapor	Specific heat capacity Liquid	Specific heat capacity Vapor	Enthalpy of vaporization	Viscosity Liquid	Viscosity Vapor	Prandtl number Liquid	Prandtl number Vapor	Surface tension
	[kg/m^3]	[kg/m^3]	[kJ/kgK]	[kJ/kgK]	[kJ/kg]	[µPas]	[µPas]	-	-	[N/m]
Water$|_{T=20^oC}$	998,16	0,017314	4,1844	1,9059	2453,5	1001,6	9,5441	7,0038	0,99796	0,072736
Water$|_{T=120^oC}$	943,11	1,1221	4,2435	2,1770	2202,1	232,03	12,927	1,4412	1,0245	0,054968
Water$|_{T=230^oC}$	827,12	13,985	4,6876	3,5285	1812,7	116,19	16,705	0,84930	1,2710	0,030736
Acetone$|_{T=20^oC}$	790,19	0,60104	2,1311	1,3670	539,22	321,92	7,8834	4,3642	0,78253	0,023678
Acetone$|_{T=120^oC}$	666,00	12,697	2,4828	2,0340	420,97	148,83	10,768	3,1184	0,94454	0,010761
Acetone$|_{T=230^oC}$	394,19	161,18	8,9955	16,105	118,98	71,900	25,772	7,7122	6,1628	0,00020455

References

[1]. Faghri, A. *"Heat Pipe Science and Technology"* Taylor & Francis Inc, 1995

[2]. Reay D.A., Kew P.A, McGlen R.J, *"Heat Pipes, Theory, Design and Applications"*, 6th Edition, Elsewier, 2014

[3]. Szymański P. *"Badania wpływu efektu kapilarnego na wydajność parownika obiegowej rurki ciepła"* Rozprawa doktorska Politechnika Gdańska Gdańsk, 2014

[4]. Mikielewicz D., Szymański P. „Rurka ciepła z pętlą obiegową jako urządzenie do odzysku ciepła", Technika Chłodnicza i Klimatyzacyjna, nr. 6-7, s.298-306, 2011

[5]. Storring S „*Design and Manufacturing of Loop Heat Pipes for Electronics Cooling"*, PhD Thesis, Carleton University (Canada), 2006