Research on the Selection of Low Temperature Aluminum Heat Pipe Working Fluid

Yue Yang[a], Yamei Li[b], Yang Fu[c], Guoyou Xu[d], Ziyi Zhen[e], Yating Wang[f], Xiang Gou[g]

School of Energy and Environmental Engineering, Hebei University of Technology, Tianjin, 300401, China

[a]email: 1324170284@qq.com, [b]email: 2515107034@qq.com, [c]email: 234589299@qq.com, [d]email: 764892290@qq.com, [e]email: 502055568@qq.com, [f]email: 1104605586@qq.com, [g]Corresponding author email: gouxiang@sina.com

Keywords: heat pipe; heat transfer; working fluid; acetone

Abstract. Heat pipe is a kind of high efficient heat transfer element, which is widely used in all aspects of life, especially in solar energy technology and permafrost. This research focuses mainly on the low temperature gravity heat pipe working fluid and discusses the influence of refrigerant thermos-physical characteristics to heat transfer. It is shown that the aluminum heat pipe optimal refrigerant is acetone.

Introduction

Heat pipe is a heat transfer components which relies on its phase change to achieve the effect. Due to its high thermal conductivity, excellent isothermal advantages, it is widely used in aerospace and the modern industrial manufacturing field, especially all kinds of heat exchanger and the cooler [1].

There are two types of heat pipe mainly. One is the classic heat pipe, and the other is the gravity heat pipe [2]. The working fluid in the heat pipe absorbs heat from evaporation section and rises to condensation section to emit heat, and then returns to evaporation section by its own gravity. Since the gravity heat pipe is simple in structure, easy to manufacture and low cost and excellent heat transfer performance, it is widely used in the field of heat exchange [3].

The tube shell of the heat pipe works as the role of isolating the working fluid and the environment, so it must be sealed. Because of the near vacuum environment in the pipe, it must withstand the pressure difference between the internal and the external. At the same time, it also cannot react with the working fluid. [4].

The selection of heat pipe working medium

The heat pipe discussed in this paper is made of aluminum alloy. The selection of the working fluids mainly considers the following questions:

(1) The working fluid should be compatible with the shell material.

(2) The saturation vapor pressure of the working fluid should be suitable at the heat pipe working temperature.

(3)The condensation point and boiling point of the working fluid should be in accordance with the working temperature range of the heat pipe.

(4)The working fluid should have good characteristics of thermal stability, economy, safety and environmental protection.

(5) Working fluid should have good thermal physical properties [5].

The working fluid should be compatible with the shell material. The commonly used working fluids of the heat pipe and the compatible shell materials at different operating temperatures are shown in Table 1 [6].

Table 1 Common working fluid of heat pipe

Species	Working fluid	Working temperature/℃	Compatible material
Low temperature heat pipe	Ammonia	-60-100	Aluminum, Stainless steel, Low-carbon steel
	R-21（$CHCl_2F$）	-40-100	Aluminum, iron
	R-11（CCl_3F）	-40-120	Aluminum, Stainless steel, Copper
Normal temperature heat pipe	Hexane	0-100	Brass, Stainless steel
	Acetone	0-120	Aluminum, Stainless steel, Copper
	Ethanol	0-130	Copper, Stainless steel
	Methanol	10-130	Copper, Stainless steel Carbon steel
	Toluene	0-290	Stainless steel, Low-carbon steel, Low-alloy steel
	Water	30-250	Steel, Carbon steel （Which inner wall was treated chemically）
Moderate temperature heat pipe	Naphthalene	147-350	Aluminum, Stainless steel, Carbon steel
	Diphenyl	147-300	Stainless steel, Carbon steel
	Dowtherm -A	150-395	Copper, Stainless steel Carbon steel
	Dowtherm –E	147-300	Stainless steel Carbon steel, Nickel
	Mercury	250-650	Austenitic stainless steel
High temperature heat pipe	Potassium	400-1000	Stainless steel
	Cesium	400-1100	Titanium, Niobium
	Sodium	500-1200	Stainless steel Kang Ni alloy
	Lithium	1000-1800	Tungsten, Tantalum、Molybdenum, Niobium
	Silver	1800-2300	Tungsten, Tantalum

Appropriate melting, boiling point, coagulation point and boiling point of working fluids should conform to working temperature range of the heat pipe.

Heat pipe working temperature should between the freezing point and critical point of working fluids . The discussion of this article pays attention to the low temperature heat pipe whose working temperature is 72℃.

Table 2 Comparison of thermal physical properties of different working fluids

Working fluids	25℃Saturated vapor pressure /MPa	Atmospheric pressure boiling point /℃	Working temperature/℃	Critical temperature /℃
Ammonia	1.00	-33	-60-100	------
R-21	0.18	8.9	-40-100	------
R-11	0.11	24	-40-120	------
Acetone	0.03	57	0-120	235.5
Naphthalene	0.0004	217.9	147-350	------
HFE7100	------	61	------	195.3
PF5060	0.03	56	------	177.85
PF5050	2.13	30	------	149.85
PF5052	0.04	50	------	180.85
XF4310	0.03	55	------	------
DR-2	0.07	------	------	------
R134a	0.67	-26.1	------	101.1
R113	0.045	45.7	------	214.1

At the same time, for the texture of aluminum tube is soft, which leading to the bearing capacity of heat pipe also will be affected by certain restrictions. The tube thickness in this paper is 0.9 mm, the diameter of aluminum tube is 22 mm. The formula of the heat pipe maximum working pressure is shown as follows [7]:

$$[P] = 2[\delta]^t s/(d_i + s) \quad (1)$$

[P]- Maximum working pressure, MPa

$[\delta]^t$ - Operating temperature material allowable stress, MPa

s - Wall thickness, mm

d_i- Pipe diameter, mm

Working fluids should have good thermal stability, economy, safety and green environmental protection. It is found that destruction of R-11and R-21 to the ozonosphere is very serious. Therefore, these two kinds of working fluids are not recommended. Acetone has small influence on environment and it belongs to flammable material. Furthermore, the working temperature of heat pipe is 72℃ and the highest temperature of the evaporation section is not up to 120℃. Acetone ignition point is 465℃. So acetone is appropriate.

For the working fluid in the heat pipe, the liquid phase transmission coefficient is the physical property of heat pipe that should be considered first. Theoretically speaking, the liquid phase transfer coefficient reflects the heat transfer power. Therefore, the greater of the liquid phase transfer coefficient of the working fluids, the more favorable of the heat pipe heat transfer coefficient. The formula of liquid phase transfer coefficient is shown follows [8]:

$$N_l = \sigma\rho_l h_{fg}/\mu_l \quad (2)$$

N_l- liquid phase transfer coefficient

σ-Surface tension of working medium, N/m

ρ_l- working fluid density, kg/m^3

μ_l-Viscosity, N.S/m^2

h_{fg}-Latent heat of vaporization at the operating temperature, kJ/kg

The liquid phase transfer coefficients of three working fluids at different temperatures are compared in the following figure:

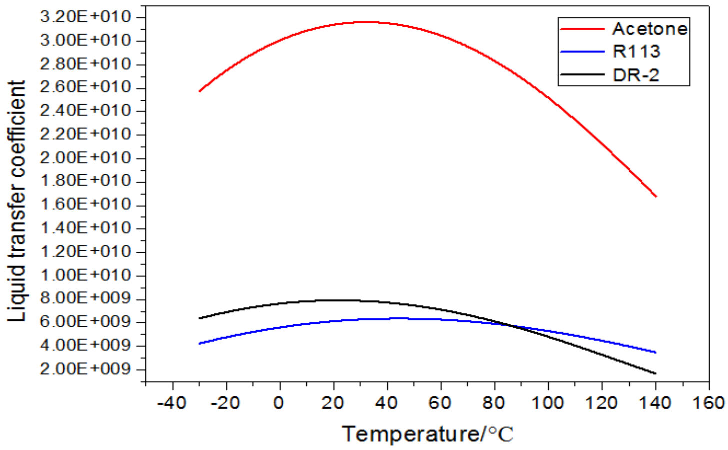

Fig. 1 liquid phase transfer coefficient -temperature curve

It can be seen from the graph, the liquid phase transfer coefficient of different materials has a maximum value. In addition , the liquid phase transmission coefficient of acetone is much larger than R113 and DR-2. The liquid phase transfer coefficient of R113 and DR-2 is almost the same around 83 ℃. When the temperature is less than 83 ℃, the liquid transmission coefficient of DR-2 is slightly larger than R113.

Advantages of acetone -aluminum heat pipe

The heat load of heat pipe exchanger is 10kw. Through the design and check of the radiator structure, there are 2 cases for choice:

Case1. The diameter of heat pipe is 19.27mm, the single heat pipe heat load is 454.55W, there are 22 heat pipes in the exchanger;

Case2. The diameter of heat pipe is 19.27mm, the single heat pipe heat load is 416.67W, there are 24 heat pipes in the exchanger.

Heat load limit of heat pipe

The heat load limit-temperature curves are drawn in the Fig. 2.

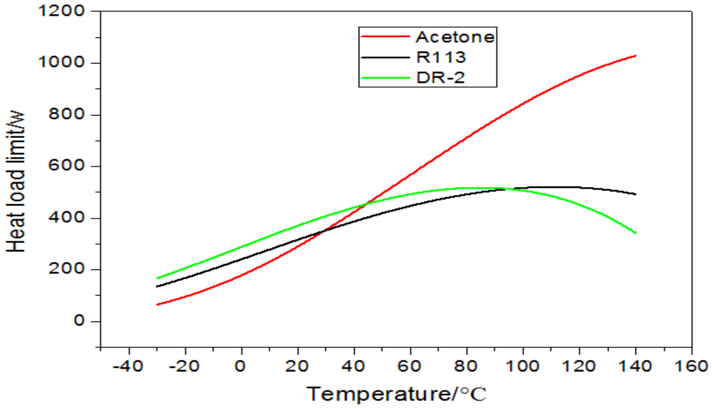

Fig. 2 Heat load limit-temperature curves

It is shown that the acetone heat load increases exponentially with the increase of temperature and is higher than R113 and DR-2, not only because the large evaporation latent heat of acetone, but also the density of the liquid phase and gas phase is less than the other two working fluids at the same temperature.

Carrying limit of heat pipe

When the heat load of heat pipe increase, the speed of vapor turns large, at the same time the steam and reflux film friction increases, then the liquid working fluid will be carried by the steam flow. This phenomenon hinders the normal flow of condensate and makes the evaporation section over heat, which causes a heat transfer limit [9]. The calculation formula of the carrying limit of the heat pipe is as follows：

$$d_c = \sqrt{\frac{1.78Q''}{\pi\gamma(\rho_l^{-0.25}+\rho_v^{-0.25})^{-2}[g\sigma(\rho_l-\rho_v)]^{0.25}}} \quad (3)$$

d_c—Diameter under the carrying limit, m

Q'' —Heat transfer under the carrying limit, kW

γ—Latent heat of vaporization, kJ/kg

ρ_l ρ_v—Vapor - liquid density, kg/m^3

σ—The liquid surface tension, N/m

g—Acceleration of gravity, m/s^2

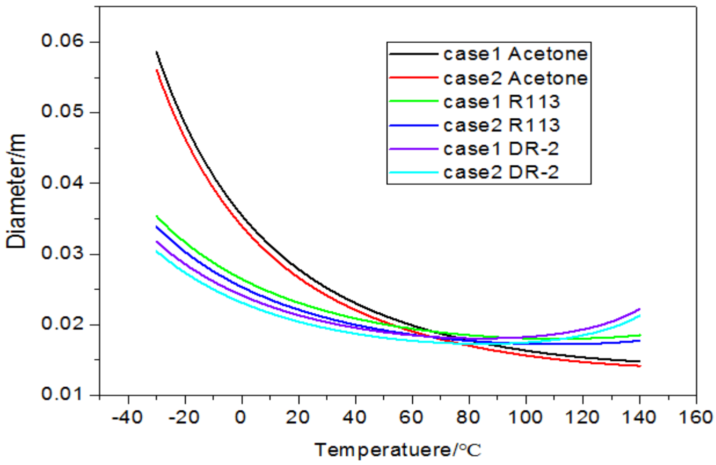

Fig. 3 Diameter-temperature curves under the carrying limit

The diameter of heat pipe is limited by carrying limit, which requires the design diameter should be bigger than the carrying limit's. Fig. 3 shows when the temperature is below 60℃, the heat pipe diameter under the carrying limit of acetone is bigger than the other two working fluids. While the temperature is over 60℃, with the increasing of temperature, the diameter of heat pipe under the carrying limit is less than the other two substances. For the heat pipe with operation temperature at 72℃acetone should be selected as working fluid.

Speed of sound limit of heat pipe

The designing value of the heat pipe diameter should more than the speed of sound limit under the working temperature. The speed of sound limit is calculated as follows:

$$d_v = 1.64\sqrt{\frac{Q_c}{\gamma(P_v\rho_v)^{0.5}}} \tag{4}$$

d_v—Diameter of steam flow cross section, m
ρ_v—Density of vapor in the pipe, kg/m^3
P_v—Pressure of steam in pipe, Pa
γ—Latent heat of vaporization, kJ/kg
Q_c—Heat transfer under the speed of sound limit, kW

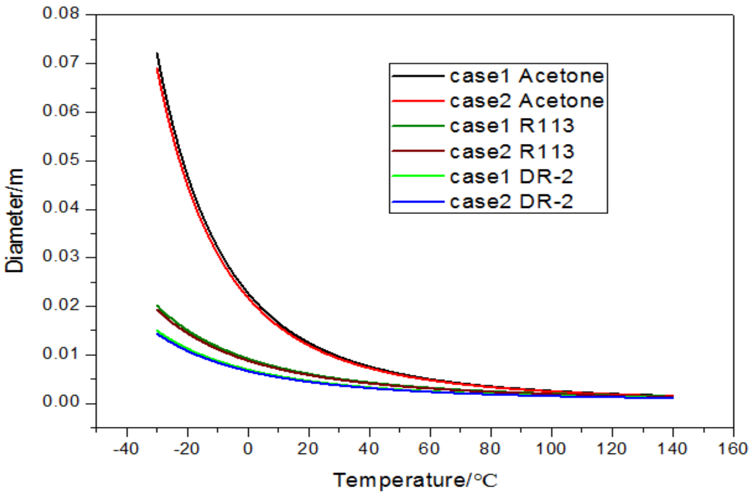

Fig. 4 Diameter- temperature curve under the speed of sound velocity limit

Fig.4 shows that the diameter of the speed of sound limit reduces with the temperature increase in the three kinds of working fluids. After the temperature is below 100℃, the speed of sound limit of acetone is more than the other two fluids'. Moreover, the diameter of the speed of sound limits are gradually stabilized over 100℃. At the same time, the diameter of carrying limit is more than the speed of sound limit at the same temperature of a working fluid.

Conclusions

Taking the design principles of heat pipe into account, acetone is not only compatible with aluminum, but also in line with the design principles of heat pipes in other aspects. Moreover, large amounts of data show that acetone has more advantages than R113 and DR-2 for aluminum heat pipe. However acetone is extremely flammable and poisonous substances, it should be careful in the process of filling heat pipe. Many studies are looking for a new working fluid to instead of acetone, while the effect of heat transfer is not verified.

References

[1] Bin Fang, Wenbin Bai. Energy-saving heat pipe exchanger of boilers and furnaces[M]. Harbin: Harbin Institute of Technology Press, 1985, 57-59.
[2] Jun Zhuang, Hong Zhang. Heat Pipe Technology and Engineering Application[M].Beijing: Chemical Industry Press,2000(5) , 50-60.
[4] M.N. Ivanovski, V.P. Sorokin, I.V.Yagedejin.Thermal physicial principle of heat pipe[M].Beijng: China Petrochemical Press, 1987, 12-25.
[5] S.W.Ji. Heat pipe theory and Practice[M]. Yanzhang Jiang translate. Science Press.Beijing. 1981, 92-96.
[6] Hongjun You. Progress in application of heat pipe technology [J]. Sichuan Chemical Industry, 2005, 5(3) ,47-50.
[7] Gang Liu. Working fluid selection of gravity heat pipe[J] . Refrigeration and Air Conditioning (Sichuan), 2006,(1) ,41-43.
[8] Guiyun Li, Jin Tu. High temperature heat pipe working medium selection [J]. Energy-saving technology , 2001 ,43-45.
[9]Lei Wang. The design and calculation of heat pipe exchanger [J]. Soda Industry, 2001,(3) ,39-41.