Design and Analysis of Double Phase Heat Pipe

IC Specification

Size:20mm X 20mm
Thickness:3mm
Thermal Conductivity:0.13 W/(cm.°C)
Process Temperature:60°C
Optimum Temperature:20°C

Energy Analysis

Heat removed from the IC is due to conduction to the heat pipe.

From Fourier's Law of Conduction,

$Q=kA(\Delta T/t)$

Now,
A=20mm X 20 mm=0.0004 m2
$\Delta T=60-20=40°C$
t=3mm
k=0.13 W/(cm.°C)

So, Q=0.13*(2*2)*(40/0.03)=69.33 W

Heat removal required:**Q=70 W**

As the process temperature is around 60°C,a suitable working fluid would be acetone(boiling point 56.08°C)

Working Fluid: **Acetone**

Now, enthalpy of vaporisation for acetone
h=534 kJ/kg

Using energy balance,

Q=Qv
=>dm/dt=70/(534 X 1000)=0.00013 kg/s

Mass flow rate:**dm/dt=0.00013 kg/s**

Pressure Drop Analysis

$\Delta P_{total}=\Delta P_v+\Delta P_l+\Delta P_g$

Pressure drop due to vapor motion,
$\Delta P_v=0$ (negligible value)

Pressure drop due to gravity,
$\Delta P_g=\rho g l \sin \varphi$
=784.5 X 9.81 X 0.15 X sin(15°)
=298.78 Pa

as ρ=784.5 kg/m3 for Acetone
φ=inclination=15° (from design)
l=effective length=150 mm (from design)

Pressure drop due to liquid,
$\Delta P_l=\mu Q l/(\rho h A K)$

Now,
ρ=784.5 kg/m3 for Acetone
μ=0.309 cP for Acetone
h=534 kJ/kg for Acetone
Q=70 W
l=150 mm (from design)
K=wick permeability
It is calculated using Blake-Koseny equation,

$$K = \frac{d_w^2 (1-\varepsilon)^3}{66.6\varepsilon^2}$$

where dw=wick twist length=0.025 mm
ε=0.314 (for standard 150 mesh wick)

So we get,
$K=3 \times 10^{-11}$

Hence,

$\Delta Pl=0.0258/A$

Therefore,

$\Delta Ptotal=298.78+0.0258/A$

For effective operation,

$\Delta Ptotal<\Delta Pc$

Here,

ΔPc=capillary pressure in wick

$=2\sigma \cos(\theta)/r$

Now,

σ =surface tension=0.02308 N/m for Acetone

$\theta=0°$ assuming perfect wetting

r=0.04097 mm (for 150 mesh wick)

So, ΔPc=1126.68 Pa

For critical condition,

$\Delta Ptotal=\Delta Pc$

=> A=0.0000312 m2

=> d=0.0063 m

=6.3 mm

Available pipe size near this value is 6mm

Pipe diameter:**d=6mm**

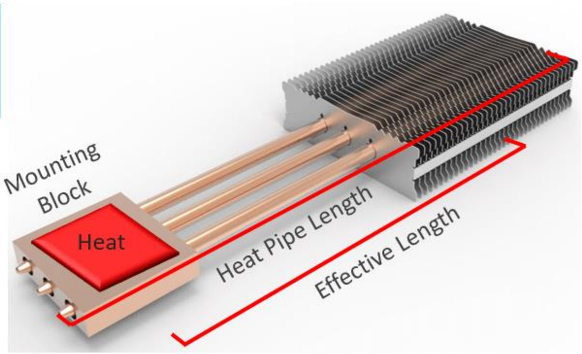
Total Pressure Drop:**ΔPtotal=1127 Pa**

Design Analysis

Thermal conductivity of a heat pipe varies with length.

From experimental data we have,

Heat Pipe Length (mm)	Effective Length (mm)	Effective Thermal Conductivity (W/m-K)
75	25	10,000
100	50	17,000
150	100	30,000
200	150	44,000



Reference:https://celsiainc.com/blog-heat-pipe-design-considerations-pt-1/

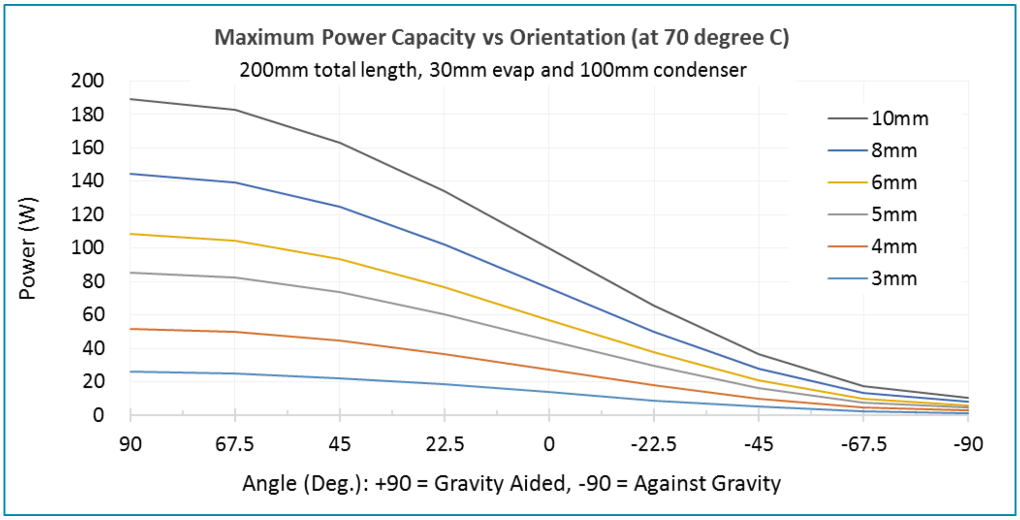
So maximum thermal conductivity is obtained when length is chosen to be 200mm.If length is increased furthermore the increment of conductivity is not very cost effective.Hence optimal length is 200mm.

Length of heat pipe:**L=200 mm**
Effective length:**l=150 mm**

As for material we choose copper with powder sintered wick.The working fluid has a capillary pressure of 1127 Pa.So appropriate wick would be 150 mesh uniform wick.

Material:**Copper with powder sintered wick of 150 mesh**

For orientation we have,



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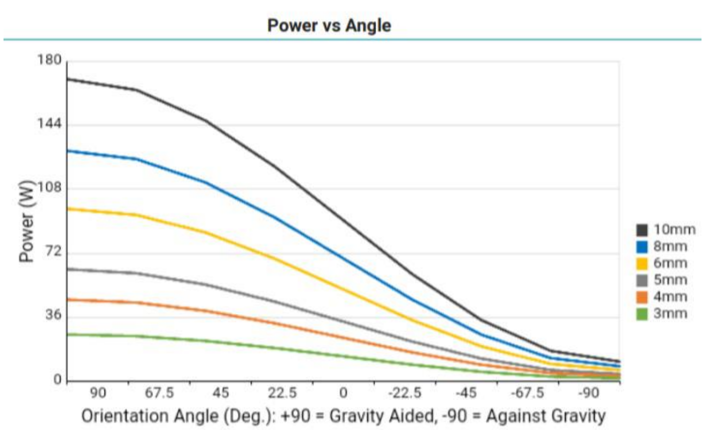
Our requirement is 70W of heat removal and the pressure drop analysis shows that diameter should be 6 mm.So from graph we get appropriate bending angle is 15°.

Bend angle:**15°**

For energy calculation we used an online calculator.From that calculation,



Reference:https://celsiainc.com/heat-pipe-performance-calculator/

For 15° angle and 6 mm diameter from the graph we have,

q=38 W

In general,heat pipe is designed buffering 25% of it's capacity for safe performance.
Also due to each bend the pipe loses 2.5% of it's capacity.In our case we have 2 bends so a total of 5% capacity is lost due to bending.

So finally,

$q=27$ W

Our operation requires $Q=70$ W

So total number of tubes needed,

$n=Q/q=70/27=2.59=3$ (nearest integer)

Number of heat pipes:**3**

On the condenser side we have fins for heat dissipation.

Total volume of finned portion,

$V=QR_v/\Delta T$

Now,

$Q=70$ W

$T_{process}=60°C$

$T_{air}=25°C$

$\Delta T=60\text{-}25=35°C$

R_v=volumetric thermal resistance

Air Flow (m/s)	Volumetric Thermal Resistance: Rv (cm^3 – C/W)
Natural Convection	500-800
1 m/s (gentle air with very low noise)	150-250
2.5 m/s (moderate air)	80-150
5 m/s (fast and loud)	50-80

Reference:https://celsiainc.com/blog-heat-pipe-design-considerations-pt-2

In our design we are using a cooling fan for heat flow enhancement.According to it's specification it has a speed of 2.5 m/s.

So, $R_v=100$ (cm3-°C/W)

Therefore, V=0.0002 m3

Generic fin thickness=1.5 mm
Fin spacing for optimum convection=2.5 mm
Condenser length=100 mm
So, number of fins,

$N=100/(1.5+2.5)=25$

Number of fins:**25**

Now,

$V = N A_f t$

$\Rightarrow A_f = 0.0002/(50 \times 0.003) = 0.00133$ m2

So an appropriate fin size would be,

9.5 cm X 3.5 cm(with allowance)

Final Design

Mounting Block	30mmX30mm
Pipe Length	200mm
Evaporator Length	30mm
Transport Length	70mm
Condenser Length	100mm
Incline Angle	15°
Pipe Diameter	6mm
Wick Size	150 mesh
Pipe number	3
Fin thickness	0.5mm
Fin size	9.5cmX3.5cm
Fin number	50