Section 2: Problem (1)

A core processor chip in a PC dissipates 100W of heat. The user has attached a liquid-channel cooling block directly to it, through which coolant liquid can flow.

The user has a choice between water or a non-conductive modern liquid coolant with GWP=0 (3M NOVEC® 649 [2.2]). What is the mass flow $\dot{m}$ of (1) water and (2) 3M NOVEC® 649 needed to ensure that the coolant liquid temperature rise ΔT is limited to 10 ˚C?

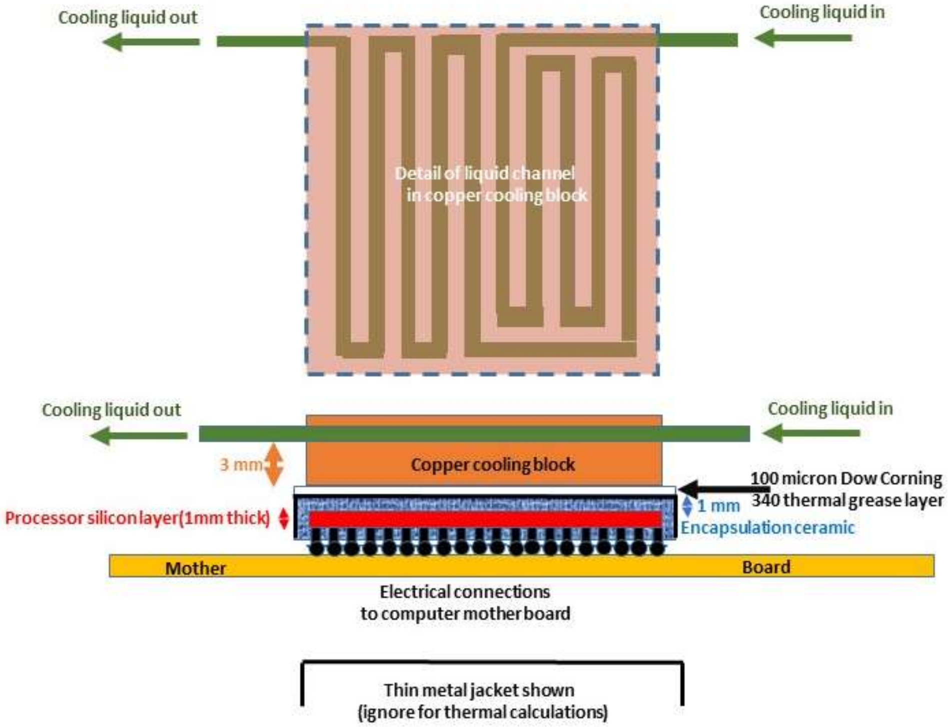
In practice of course, heat must be channelled into the cooling fluid. To do this it must flow through the thickness of the core processor chip silicon package, through the adhesive or thermal grease that bonds it to the cooling block and through the wall of the cooling block into the fluid. All these materials have thermal resistances which add up, resulting in the silicon chip operating at a higher temperature than the cooling fluid circulating through the block. We will revisit this later.

Section 2: Problem (2)

A core processor chip in a PC dissipates 100W of heat. The chip has a (4 cm x 4 cm) square profile. The user has attached a (4 cm x 4 cm) square channelled copper block on top of it, through which coolant liquid can flow to cool the processor. The cooling block makes contact with a thin metal jacket on top of the chip through a 100 micron layer of Dow Corning 340 thermally-conducting grease (see table 2.2 for characteristics).

The processor chip package itself is 3 mm thick in total (as illustrated in the figure), made from a 1 mm-thick active silicon layer that is centrally-sandwiched with 1 mm of ceramic encapsulant above and below it. The ceramic fill has a thermal conductivity of 200 $Wm^{-1}.K^{-1}$.

Note: in this simplified thermal model the heat can be thought of as being dissipated in a single layer of doped semiconductor implanted into the surface of the active silicon layer ***facing down*** towards the connector to the mother board. Heat must therefore pass through 1 mm of active silicon substrate another 1 mm of ceramic encapsulant in the opposite (up) direction on its way to the cooling block. Any heat loss by conduction through the connector pins to the mother board can be ignored. The very small thermal resistance of the thin topside metal jacket can also be neglected in the calculation; you can pretend that it isn't there (it is shown displaced - just for reference).



Thermal paths in the cooling of a silicon processor chip (local channel)

The heat from the chip can therefore be thought of as passing through 1 mm of active silicon and a further 1 mm of ceramic encapsulant before passing through a 100 micron (0.1 mm) thick layer of Dow Corning 340 thermal paste, and finally through the copper cooling block with an effective thickness of 3 mm before reaching the cooling liquid channel, as shown in the figure.

Coolant enters the cooling block and follows a tortious path to try to extract heat as uniformly as possible. The high transverse thermal conductivity of the copper block helps spread the heat transversely over the whole (4 cm x 4 cm) between the wiggles of the coolant channel.

Problem (2) questions;

For the first 4 questions you can consider that the coolant to enters the block 20 ˚C and leaves at 30 ˚C. The average temperature in the copper block cooling channel can be taken as 25 ˚C.

What are the (progressively-increasing) temperatures on the following surfaces;

- The surface of the copper block in contact with the top face of the Dow Corning 340 thermal grease film (**A**)? (This is 3mm from the plane of the coolant channel)
- The surface of the ceramic in contact with the bottom face of the 100 micron Dow Corning 340 thermal grease film (**B**)?
- The hot (downfacing) side of the1 mm thick processor chip itself (**C**)?

  Note: you have to consider the thermal resistance of two materials in series to get to this figure.
- Which material contributes the biggest temperature difference (temperature difference across itself)?
- What method would you use to reduce the contribution of this layer (mechanical solutions acceptable)?

Building on this knowledge…

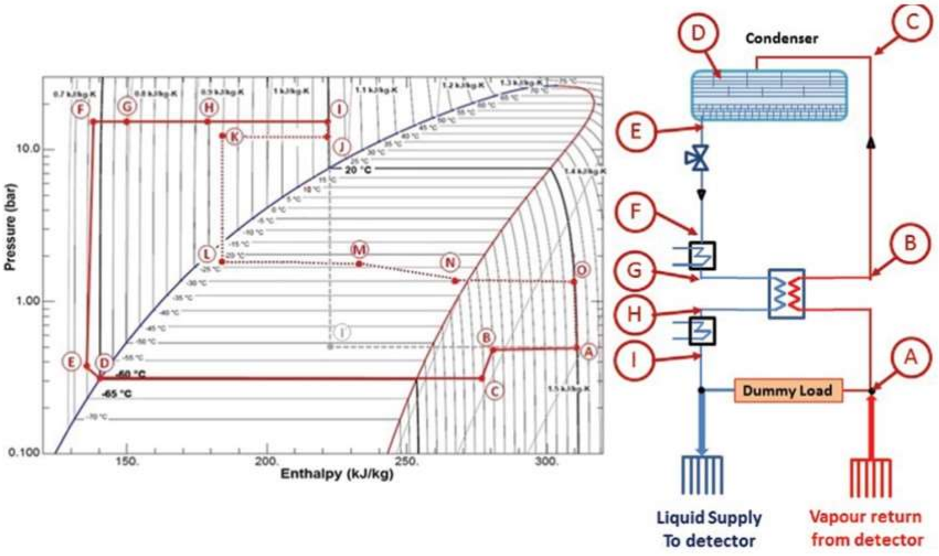
The user has a choice between water or a non-conductive modern liquid coolant with GWP = 0 (3M NOVEC® 649 [2.2]), but the pump available can only circulate a maximum of 3 grams per second (a mass flow of 0.003 kg.s^{-1}) of any liquid. What is the input temperature of NOVEC 649 to the copper cooling block to maintain an average temperature in the block cooling channel of 25 ˚C? (Hint: this calculation uses the concept of coolant heat capacity and mass flow from the previous problem.

Section 3 problem (1)

From Fig. 3.9 it was clear that a large number of tubes are needed to condense approximately 1.2 kg.s^{-1}of C_3F_8 to cool the ATLAS silicon tracker. This implies that a high mass flow of C_6F_{14} liquid is needed, but what this mass flow (kg.s^{-1})?

Hints to solve this problem:

- Looking at figure 3.10 we see that considerable thermal energy has to be extracted from the C_3F_8 vapor to reduce its temperature from around 20 ˚C (the temperature acquired in traveling through more than 92 meters of pipes to the condenser) to -60 ˚C, where phase change can occur under the “dome”;
- Some of this heat is extracted from the vapour at a C_3F_8 pressure of 320 mbar within the condenser itself (using a counter-flow of cold C_6F_{14}), cooling the vapor from -25 ˚C (point **C**) to -60 ˚C before the vapour begins to condense at the saturated vapour boundary of the dome.
- Moving left from the saturated vapour boundary of the dome all energy goes into condensing the C_3F_8.
- You should therefore use the entire **CD** enthalpy difference in your calculation, and only this;
- The specific heat capacity of C_6F_{14} in the range -60 ➔ -65 ˚C is around 925 J.kg^{-1}. C_6F_{14} remains a liquid and does not change phase during this process, but heats up by 5 ˚C.



Section 3 Problem (2)

A processor chip dissipating 75W needs to be cooled by conducting heat away to a finned heat exchanger (the heat sink). The cooling block in contact with the chip through a thin thermal grease joint has grooves for three 6 mm diameter heat conduits, as shown in the figure. The total cooling path from the center of the cooling block to the center of the finned radiator is 15 cm. The fan is powerful enough (and has enough range of driving voltage) to keep the heat sink at 40˚ C under all circumstances. This temperature is maintained by feedback from a temperature sensor mounted near the fan itself (note the 4-wire connector in the photo montage).

The computer user notices that, after turn-on the processor chip (monitored by its own internal temperature sensor) rapidly increases to over 12 ˚C higher than its normal operating temperature before the system annoyingly takes remedial action by decreasing the processor clock frequency etc. Doing some research the user finds that this cooling configuration uses three low-pressure water-filled copper heat pipes with 1mm wall thickness and a nominal thermal conductivity 20000 $W.m^{-1}.K^{-1}$ and surmises that one might have failed (leaked up to atmospheric pressure).

- Would the user be correct in this assumption?
- Why, or why not? Show your reasoning with a calculation.

Hint: a failed heat pipe would revert to the thermal conductivity of a copper tube of 6mm outer diameter and 1mm wall thickness.

Section 3 Problem (3)

Part of the Larsen-C ice shelf broke off from Antarctica in July 2017 and drifted North as iceberg A-68 before melting away. A-68 was 170 km long, 50 km wide with an average thickness of 200m.

(a) Using the Latent heat of fusion ***L*** of water (333 kJ.kg^{-1}) estimate the combined energy absorbed from the sea and atmosphere to melt A-68.

(b) Let's assume that the energy from (a) comes from global warming.
It is estimated (with big uncertainties as inspections are less frequent than they used to be) that the World's stockpile of nuclear weapons is around 10 000 megatonnes of TNT equivalent. The explosion of 1 megatonne of TNT has an energy release of around 4.2.10^{15} Joules. What percentage of the World's 10000 Mt stockpile of nuclear weapons would need to be exploded to melt iceberg A-68? (Assume all the energy goes into melting ice). How many gigajoules is that?

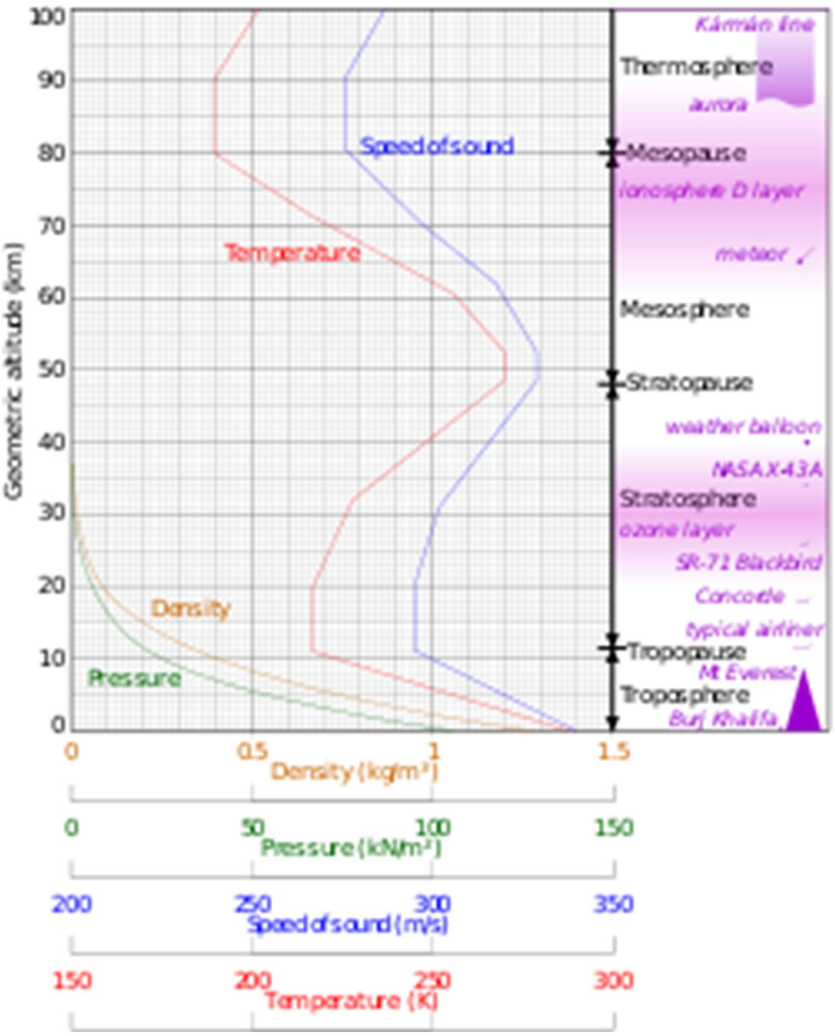
(c) Now let's pretend that A-68 never existed (i.e. that there is no ice to buffer atmospheric heating), and that the global warming energy calculated from (a) above went instead into heating the Earth's atmosphere. Taking the Earth's radius as 6370 km and assuming the effective atmospheric depth to be 16 km (this height contains more than 90% of the atmospheric mass), how much would the atmospheric mass be raised in temperature?

(d) Should we be worried? Why, or why not?

Hints

(1) use "average values" of the ***Cp*** (1.0036 kJ.kg^{-1}.K^{-1}) and density of air (0.45 kg.m^{-3}) [3.1] at the temperature of – 43˚C and pressure (0.3 bar$_{abs}$) [3.5] , corresponding to an altitude of 8 km: half the 90% mass height of 16 km;

(2) The average sea depth is 3688 metres and sea covers 71% of the Earth's surface. Oceans hold 96.5% of the Earth's water. According to the U.S. Geological Survey, there are over 1,386,000,000 cubic kilometers of water on the planet. Of this vast volume NOAA's National Geophysical Data Center estimates that 1,335,000,000 cubic kilometers is in the oceans. Ocean water mass = 1.335. 10^{18} tonnes.



Geometric altitude (km)
100
90
80
70
60
50
40
30
20
10
0
Kármán line
Thermosphere
aurora
Mesopause
ionosphere D layer
meteor
Mesosphere
Stratopause
weather balloon
NASA X-43A
Stratosphere
ozone layer
SR-71 Blackbird
Concorde
typical airliner
Tropopause
Mt Everest
Troposphere
Burj Khalifa
Speed of sound
Temperature
Density
Pressure
0
0.5
1
1.5
Density (kg/m³)
0
50
100
150
Pressure (kN/m²)
200
250
300
350
Speed of sound (m/s)
150
200
250
300
Temperature (K)

Section 7 problem (1)

Last problem: – one for the sleuth: while a new fluid C_3F_6O would have all the advantages of C_3F_8, but with zero GWP, the thermodynamics of C_3F_8 and presumably of C_3F_6O (which differs in molecular weight by 22 units) is not perfect for cooling a processor chip at room temperature. What fluid in the $C_nF_{2n}O$ spectrum might be better, and why?

Hint: the SFC progression of fig 7.2 may help in this.