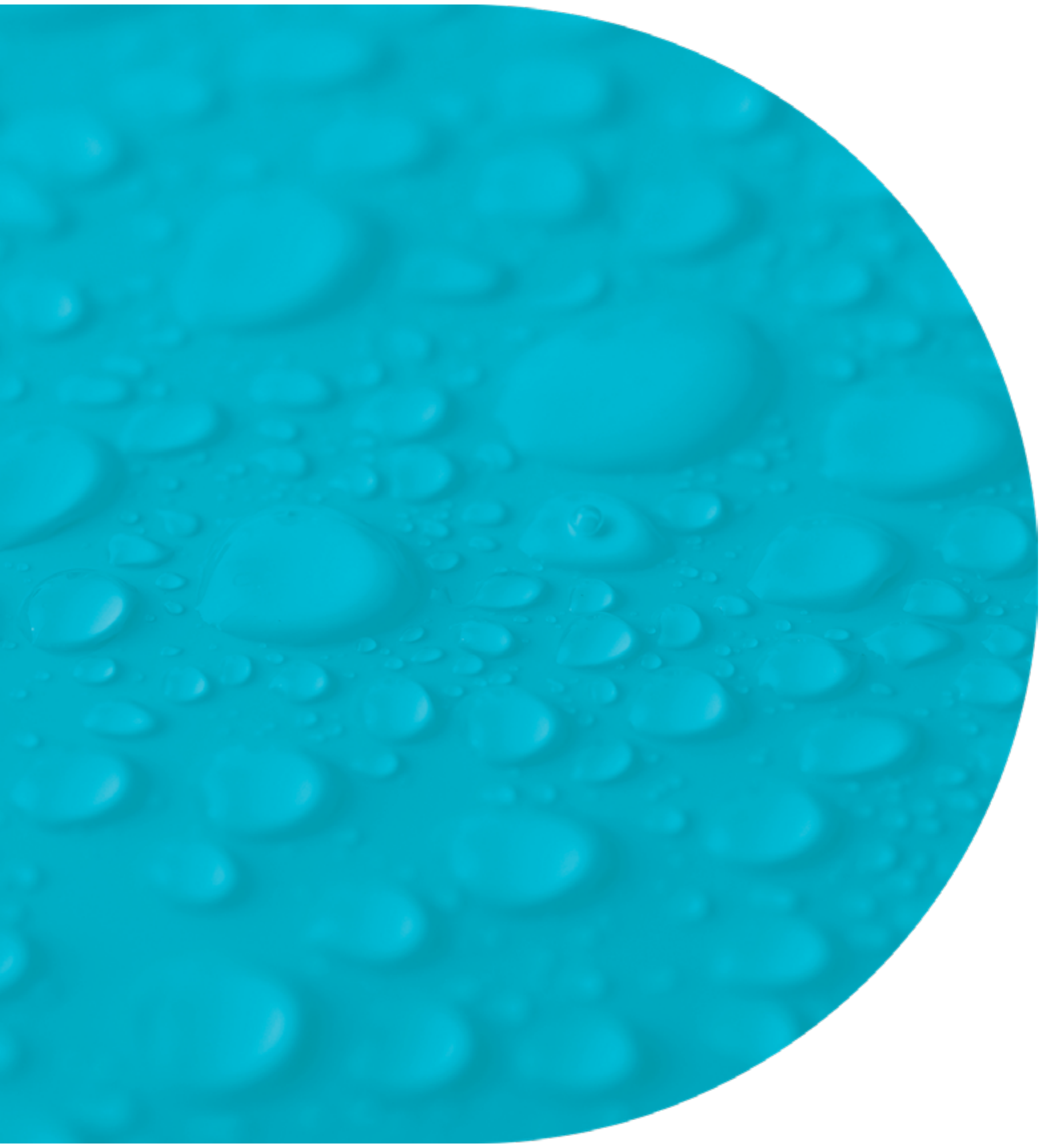
White paper
Thermodynamics



The Convection Principle:
What it is and how it applies to
Submer's Immersion Cooling Technology

submer

Datacenters that make sense

About the author

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MSc in Aerospace Engineering and Specialist's Degree in Fluid Mechanic, Jaime started his professional career developing aero-engines for ITP, one of the leading companies in the aeronautics sector in Spain.

After specialising in CFD, he started working for Indra, improving his knowledge of cooling for electronics thanks to the development of air-cooled solutions for radar and electronic countermeasures for fighter aircraft.

In the UK, he worked for the environmental protection team in Rolls-Royce plc, analysing inclement weather phenomena and its effects in the thermal performance on aero-engines, then as a Team Lead for aero- and thermodynamics in Bombardier Transportation.

Table of Contents

1. Introduction

High temperatures in **electronics** have always been a **problem** for their **performance** and **lifespan**. This problem has been dealt with in two ways:

- By means of **cooling** with the surrounding air by accelerating it (using fans).
- And by adding some features like channels, heatsinks, thermal paste (and some other elements that have been developed in the past years in order to achieve the **maximum energy dissipation** from the components of every motherboard).

But excessive cooling effort has three immediate consequences:

1. It wastes energy.
2. It increases costs.
3. It adds the maintenance variable to the equation.

Still, it is not a bad approach.

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> ***High temperatures in electronics have always been a problem for their performance and lifespan.***

Using the accelerated air to cool down objects is a common experience known to anybody. Think about, for example, when you blow air to cool a spoon of soup that looks definitely too hot. You also feel colder on a windy day than on a calm day. In summer, you open up the windows to create some air currents to make the room more comfortable. The principle is the same, and we apply it every day.

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> ***[...] excessive cooling effort wastes energy, increases costs and adds the maintenance variable to the equation.***

Historically, for electronics, fans and heatsinks were good enough, but in the present times, **more computation density is needed**. The chips are required to operate at their maximum limit, and one of the known problems is that **temperature affects their performance**. Those chips can withstand high temperatures, but would not it be great to have them operating in a very comfortable environment?
This is one of the missions Submer chose to achieve since the Company started the Immersion Cooling venture.

2. Operational Driver

How to improve the energy extraction from a starting point that is already pushed to its limits? The air is well known for having excellent insulating properties and examples are present in lots of common technologies: double-glazed windows, clothing, food containers, canteens... The list of objects that use the air for thermal insulation is infinite. So, **how can we think about using an insulating material for cooling down objects when its own properties are not optimal enough?**

2.1 Gas, Liquid or Solid?

The air is a gas. All substances can be classified as gases, liquids and solids. But also gases and liquids are both fluids, that is, they are made out of molecules that are in constant and random motion colliding with each other. So, **when talking about improving thermal properties the first idea that comes to mind is to substitute air with another fluid capable of extracting the energy more efficiently**. Thermally speaking, water is one of the better substances we have on Earth for heat dissipation. The problem is that **water is not compatible with electronic devices**, leaving that option as an impossible solution.

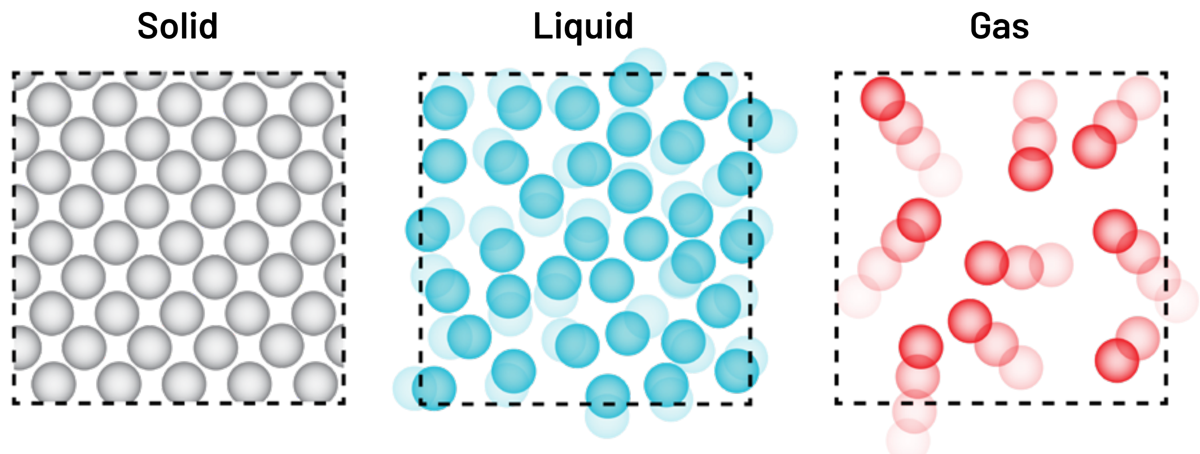

Figure 1: Molecules pattern in solid, liquid and gas substances.

3. Submer's SmartCoolant

In order to solve that problem, Submer has developed a proprietary, synthetic, dielectric fluid, called **SmartCoolant**. Since the SmartCoolant is a liquid (and not a gas), there is a base improvement due to the density of the substance (the SmartCoolant has more particles per cubic meter than air to absorb and transport energy). Moreover, the **SmartCoolant formula improves thermal properties** compared to the air, and combining it with its **dielectric properties** makes it **the best solution for cooling electronic devices**.

The SmartCoolant has a specific heat higher than air, so it absorbs the thermal energy better than air. **The mechanism of absorbing energy and driving it away from the heat source is called *convection.***

Figure 2: Conduction, con vection and radiation.

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The mechanism of absorbing energy and driving it away from the heat source is called convection.

4. The Convection Principle

Convection is one of the three mechanisms of heat transfer existing in nature (**conduction**, **convection and radiation** - see figure 2), or means of transporting energy from one zone to another on a specific domain. The **convection** principle relies on the movement of the particles of the substance to transport the energy, being this possible only on fluids, where the particles are able to flow inside the fluid domain. On the other hand, **conduction** is the transfer of energy between fixed particles (solids) and **radiation** is the transmission of energy along electromagnetic waves or subatomic particles along with vacuum or substances. A heatsink on top of a chip is a good example of:

- Conduction heat transfer, where the heat is driven away from the chip.
- And convection, where the heat is transferred to the fluid particles surrounding the heatsink and then transported away from it.

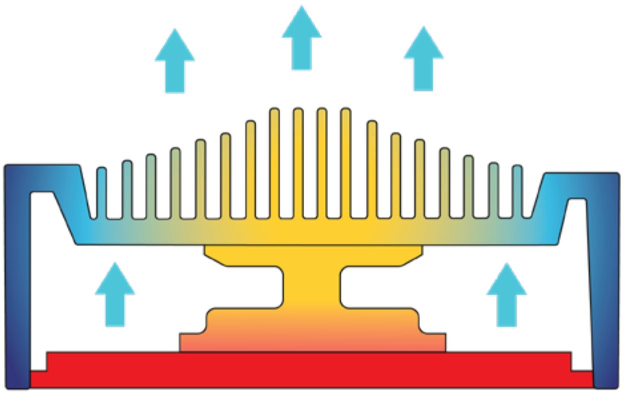

Figure 3: The conduction and convection principles in a heatsink.

As the fluid is made of particles that touch each other, some conduction will occur but the predominant effect will be the convection. Radiation can be considered negligible and therefore applicable to different types of problems.

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4.1 How the Convenction Principle Works

As specified before, **the convection principle is related to the capacity of the substance to absorb the energy and hence store it in its particles**. Those particles then will move to another part of the domain and the heat can then be transferred to another system. The capacity of the substance particles to store a certain amount of energy is called **specific heat**. This constant value measures the amount of energy that is needed to increase the substance temperature by 1 Kelvin of a certain substance quantity (usually 1 kg). **The greater the specific heat, the higher capacity a substance - in these cases, a fluid - has to store energy**. This means that a certain amount of SmartCoolant needs more energy to increase in temperature than the same amount of air, for example.

A good way to visualize this energy storing behaviour is to think of these fluid particles as waiters of a restaurant carrying a tray filled up with hot drinks. The bigger the tray (specific heat), the better, as this waiter - particle - will be able to carry more energy to different parts of the domain. **Liquids are normally better when talking about specific heat**, due to the fact that they are denser than gases. This means that the "tray" used by the SmartCoolant for storing energy is bigger than the "tray" used by the air. The energy - imagined as hot drinks - is picked up from a table (the solid) by the fluid particles. That is, in essence, heat transfer between solids and fluids. In other words, convection.

> ***The capacity of the substance particles to store a certain amount of energy is called specific heat.***

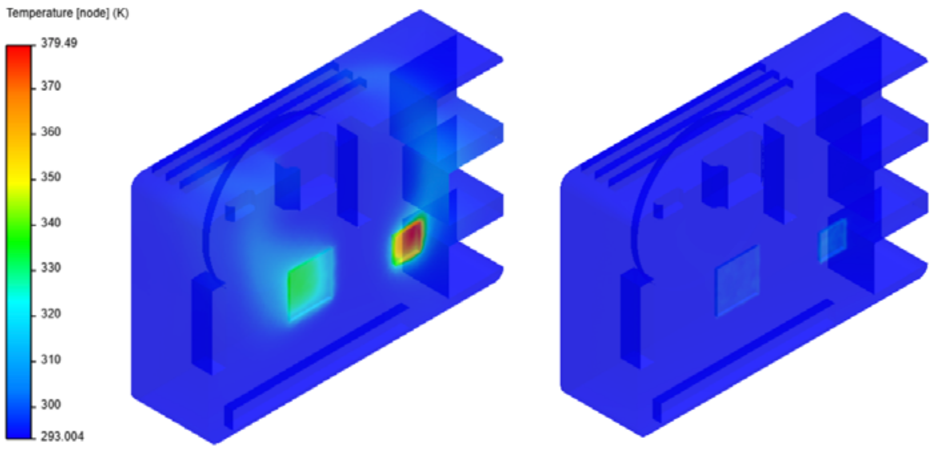

Figure 4: CFD simulations of a Raspberry Pi hardware in air (left) and in SmartCoolant (right) under the same conditions.

The convection principle is the main heat transfer method between solids and fluids. This principle is modelled normally following Newton's Law of cooling. This Law is a mathematical approximation and uses a certain parameter called heat transfer coefficient to approximate the behaviour of the thermal exchange between solid and liquid, along with the area of exchange of thermal energy. The heat transfer coefficient is the parameter that defines the amount of energy transferred from the solid to the fluid per a certain area. Newton's law of cooling can be expressed as:

$$\frac{\partial Q}{\partial t} = h_e \cdot S \cdot (T - T_\infty)$$

Where h_e is the heat transfer coefficient expressed in W/m^2K, S is the surface where the heat transfer occurs and (T-$T\infty$) is the temperature difference between the solid and the fluid. The resulting sign of this difference will give the resulting sign of the heat transfer, meaning that if the temperature difference is higher than zero the heat transfer will be positive from the solid to the fluid and hence the fluid is **extracting** heat from the solid. If the opposite occurs, then the fluid temperature is higher than the solid temperature and therefore the fluid is **applying** heat to the solid.

> ***The heat transfer coefficient is the parameter that defines the amount of energy transferred from the solid to the fluid per a certain area.***

4.2 Maximizing Convection

There are then three ways of maximizing convection:

1. **The easiest way is to act on this temperature difference** and that is by using the fluid in a cooler condition - if you want to cool down a system - supposing that the solid temperature is fixed. On the other hand, if the thermal power of the solid is fixed and the only intention is to cool it down, the resulting temperature will become lower if the fluid temperature is colder. The temperature of the fluid then plays a critical role.

2. **The second way of maximizing convection is to physically act on the surface for the thermal exchange**. Maximizing the area by modifying the morphology of a solid component is a good way of improving thermal exchange with the fluid. In some cases, this will be impossible and additional highly conductive solids with large areas of exchange need to be used. That is what we call **heatsinks**.
   Heatsinks are devices where the convection is maximized by increasing the area of exchange with fins or pins. Adding heatsinks does not act solely on the convection with the fluid, it also adds a conduction effect so **the resultant heat transfer is a combination of conduction and convection**. Acting purely on modifying convection will imply to modify the geometry of the solid that transfers the energy with the fluid.

3. **The third way of maximizing the convection mechanism is to change the morphology of the fluid, that is, selecting another fluid with a greater heat transfer**. Gases like air usually have very low values of this parameter, whereas liquids present values several orders of magnitude greater than gases. As a guideline, the typical values for the heat transfer coefficient for different substances are:

   - Free Convection - air, gases and dry vapours: h_e=0.5-1000 W/m^2K
   - Free Convection - water and liquids: h_e=50-3000 W/m^2K
   - Forced Convection - air, gases and dry vapours: h_e=10-1000 W/m^2K
   - Forced Convection - water and liquids: h_e=50-10000 W/m^2K
   - Forced Convection - liquid metals: h_e=5000-40000 W/m^2K
   - Boiling Water: h_e=3000-100000 W/m^2K
   - Condensing Water Vapor: h_e=5000-100000 W/m^2K

The **SmartCoolant** that Submer has developed relies on this concept of substituting the fluid where the hot electronic components are. **From a base point, liquids have better behaviour on convection than gases, so why not use them?** Studies over flat plate systems with the SmartCoolant fluid gave some excellent properties, as the base heat transfer coefficient for the SmartCoolant is around *500* W/m^2K (natural convection).

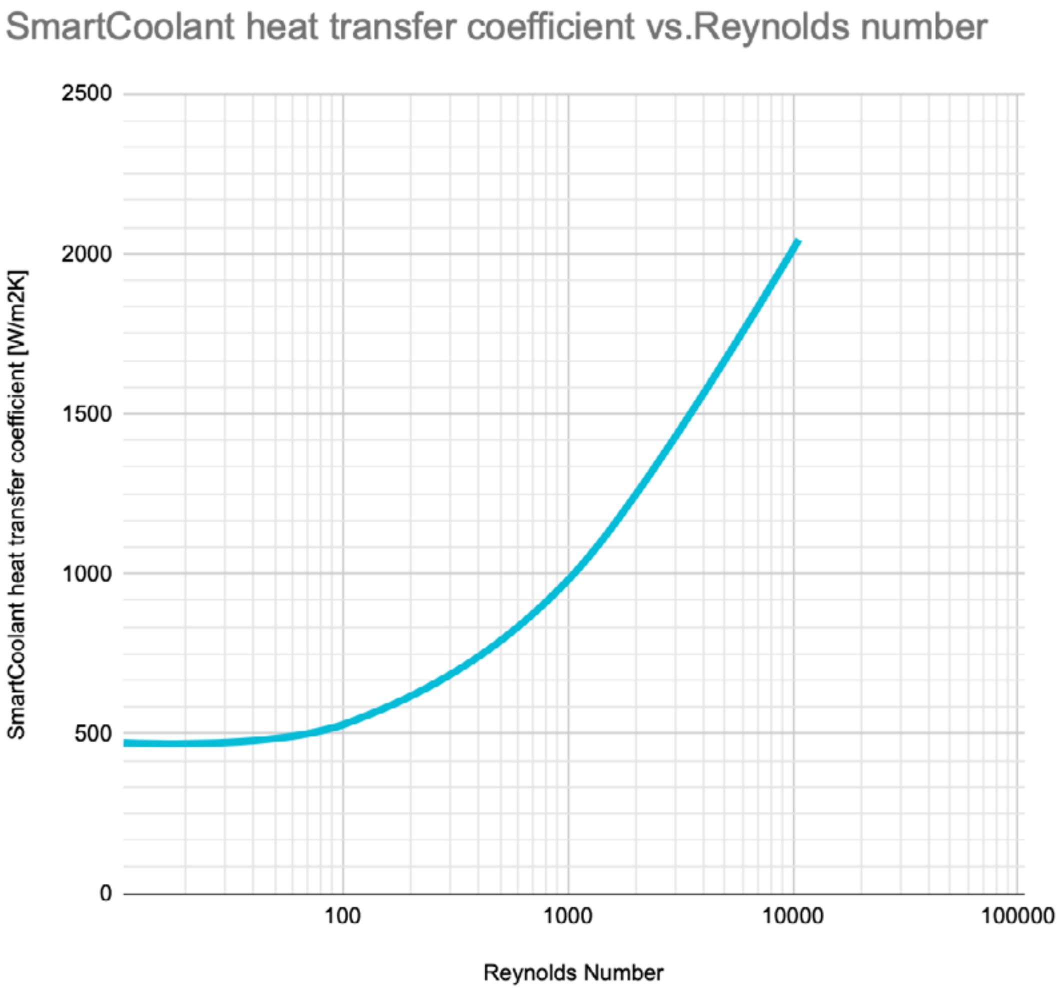

Figure 5: SmartCoolant heat transfer coefficient.

Figure 5 shows the typical behaviour for the convection coefficient of the SmartCoolant at lower velocities (left end of the graph) or higher velocities (right end). Compared to air, where the natural convection heat transfer coefficient seats in values around 0.5, it is obvious that **choosing a liquid solution is way better than a gas solution**.

Other ways of increasing the heat transfer coefficient is by accelerating the fluid in order to increase the heat exchange. In figure 5, this behaviour will be located in the right end of the chart, where the fluid has been accelerated and its capability for extracting heat increases. A good example of this behaviour is the historical mechanism of cooling IT hardware with fans and narrow channels to accelerate the air.

5. Conclusions

Using the SmartCoolant for thermal management truly represents a **game-changing** approach for the electronics industry. There are a lot of different solutions in the electronics industry for cooling down microchips and other components, but some of them are being pushed beyond their limits while the market keeps demanding for more efficient solutions. Plus, the design of heatsinks to optimise air heat transfer is expensive and in some cases, inefficient, due to the insulating nature of the air itself. The SmartCoolant gives the opportunity to improve this scenario by avoiding the use of accelerated cooling flow - no fans are needed - since the base heat transfer coefficient of the fluid is way higher than air. Also, a wide range of possibilities are available for the user if more cooling is needed, since the SmartCoolant gains thermal power extraction when accelerated, opening new scenarios to be explored.

6. About Submer

In 2015, a team of industry forward-thinkers and innovation visionaries felt that it was time for the datacenter industry to turn over a new leaf. The idea was to challenge the way datacenters are perceived and understood today and how this can create deep change in the way technology and humans behave.

Submer (https://submer.com) was born to pave the way towards next generation datacenters. We design, build and install solutions for HPC, hyperscaler, datacenters, Edge, AI, DL and blockchain applications.

At Submer, we believe that innovation can and must be sustainable. Every day we work to find the best solutions to make operating and constructing datacenters and supercomputers as efficient as possible and to have little or positive impact on the environment around them (reducing their footprint and their consumption of precious resources such as water).

Are you planning to make your datacenter smarter?
Let’s do it together!

Book a 30 minutes call with us and we’ll analyze and draw together your SmartDC strategy!

BOOK A CALL

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