Activity 3_2: natural and forced cooling

The problem:

In many cars the engine or the circuit of cooling water are cooled by forced convection. In fact, it is easily observable that the engine temperature goes down when the car is moving: air with a given velocity cools better the engine than air still with respect to the engine.

Many cars, make up for the lack of air in motion through a fan which, in effect, sets in motion the air, blowing it towards the engine.

We will try now to verify the effect of air movement in the cooling process with an experiment.

Material needed for each group:

- Two plates of aluminium (side ? 15 cm, depth ? 3mm),
- Two surface temperature sensors
- A bowl with hot water (about 90°C)
- Two plastic bags
- Two isolating supports (Styrofoam)
- A multi-speed fan

Suggestions for the experiment:

In this experiment we are going to fix, with adhesive tape, a temperature sensor on each aluminum plate and connect the sensors to the measuring system. Then, we will put the two supports of polystyrene on two tables not too close. The aluminium plates will be placed in the supports and the fan will be pointed towards one of them, facing the side where the sensor is not present.

Each plate, well sealed in a plastic bag, will be inserted into the hot water, and the temperature data collection started, waiting at least one minute, until the temperature indicated by the sensors has reached the water temperature and is stable. Then, the plates will be extracted from the water, quickly removing the bag and each plate will be put on an insulating base, as in figure

The fan will be powered and we will observe the temperature data as a function of the time that will be recorded for both plates.
The experiment is to be repeated, for the sole plate cooled by the fan, by adjusting the speed selector switch to a different fan speed.

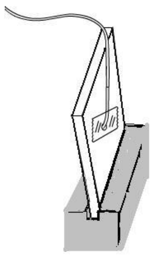


Plate 1

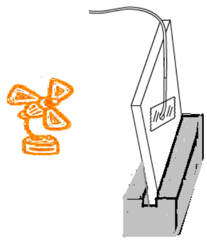
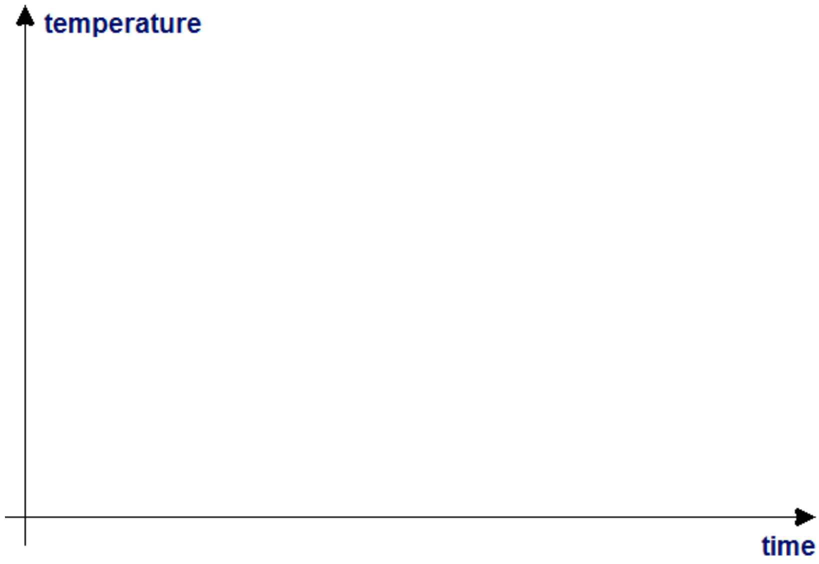


Plate 2

Make a prediction of what you are going to observe by means of the sensors. In particular, say what do you expect with respect to plate 1 and plate 2 temperatures and compare the speed with which the two temperatures will vary. Can the fan speed affect the results to be obtained for plate 2?

Now perform the experiment, as described above, and report in graphical form the results you obtained, clearly showing to which plate (1 or 2) the data refers and, in the case of plate 2, the fan speed (high, medium, low ...)



Were your prediction correct? Try to identify the points of agreement and those of disagreement between your predictions and the results you actually found.

What are the physical quantities that, in your opinion, may have influenced the results you obtained?
Briefly explain your answer, trying to differentiate between what happens during "natural" cooling (plate 1) and the "forced" one (plate 2) .

In depth analysis: experimental data fitting

It is possible to obtain an analytical expression for the cooling curves through a process of adaptation, or fitting, of a mathematical function to experimental data. This procedure is called *data fitting*.

To do this it can be useful to build a graph that reports the values of the differences, ΔT, between the values of temperature, T, detected by the sensors and the ambient temperature, T_e, as a function of time. T_e is obtained from the data table and a new column is built in the Data Logger with the values $\Delta T = (T - T_e)$. The new graph should show the trends of ΔT approaching zero and the analysis functions of the Data Logger can be used to fit the function

$$T - T_e = (T_0 - T_e)e^{-kt}$$

to the experimental data (note that T_0 is the temperature value measured by the sensor at t=0, i.e. at the beginning of data collection).

Are the mathematical functions well fitted to your experimental data? Are there values that do not adapt well to the fitting functions?
Try to discuss separately the two cases of natural and forced cooling.

____

____

____

____

____

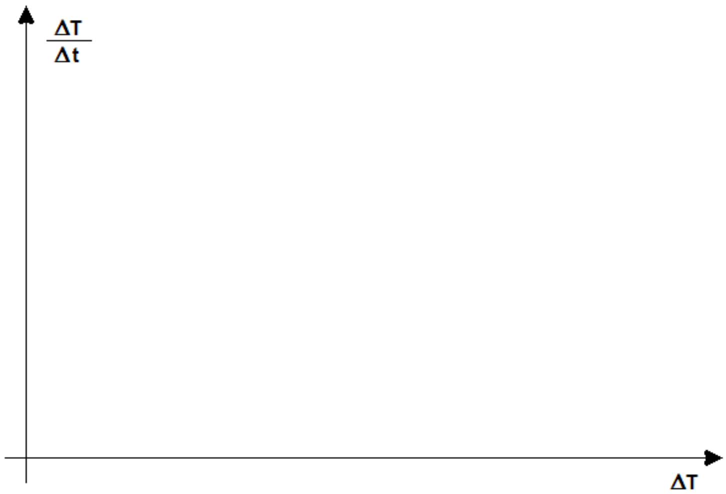
____

Describe the meaning of the variables and parameters T, T_0, T_e, k e t in the fitting functions, with respect to the characteristics the functions should have to well fit your experimental data.

In particular, highlight the variables/parameters that, in your opinion, give information about the cooling speed.

____

Another way to represent your experimental data is to plot with a spreadsheet the "cooling speed", $\Delta T / \Delta t$, as a function of ΔT, where Δt represents the time interval (constant) between two temperature, T, data. Remember that $\Delta T = (T - T_e)$, where T_e is the temperature that is reached by the plates at thermal equilibrium with the environment (i.e. the environmental temperature...).
To do this it is convenient to use the Excel file " cooling speed – data analysis.xls" that the teacher will provide you.
Report below the graphs you obtain by using produced by the spreadsheet.



Do you think that the data above represented may be fitted with linear functions?

If yes, write a mathematical relationship between ($\Delta T/\Delta t$) and ΔT ?

Is it possible to say from the experimental data and the fittings what the parameters of the linear functions (i.e. the Y-axis intercept and the line slope) actually mean?

Are there data intervals that highlight a better fitting between data and the lines than other? Try to explain.

____

____

____

____

Explanation:

From the linear dependance of (*ΔT/Δt*) vs. *ΔT* we obtain a relationship between the two variables that can be written as:

$$\frac{\Delta T}{\Delta t} = -k\Delta T$$

here k is a constant depending from the nature and shape of the cooling object and also from the way the object cools (natural or forced cooling).

The upper equation is an approximation of the differential equation

$$\frac{dT}{dt} = -kdT,$$

that has, as a solution:

$$T - T_e = (T_0 - T_e)e^{-kt}.$$

This is actually, as we have already seen before, the mathematical function that best fits the experimental data of *ΔT* vs. *t*.

Conclusions:

Try to summarize, for each of the activities you have performed, what you learned at the end of each activity and how you came to the different conclusions you have drawn.