Application Note for temperature controlled vaping

This application intends to explain the working principle of temperature controlled vaping and what should be considered by the user to achieve the best performance when vaping with a temperature controlled device.

1. Mechanical and Electronically Controlled Mod, Power, Ohm's law

On simple electric cigarettes (mechanical mods) the heater winding is connected to the battery by means of a mechanical switch or contact. According to Ohm's law the battery voltage V drives a current I through the heater's electric resistance R following I=V/R. Multiplying the current and voltage gives the heating power.
If there was no cooling liquid around the wire, it will heat up quickly to several hundred degrees C and the wire probably start to glow.
With a power/voltage/current controlled electronic cigarette, the behavior is basically the same, except that the heating power (or voltage) does not change with the battery voltage as it is kept constant by means of the electronics so it also does not depend on the resistance of the winding.

2. Hazardous Substances

As long as the winding is completely wetted with liquid, the liquid's components will be vaporized, limiting the increase in temperature to some extent. The situation changes dramatically, if there are local areas with little or no liquid or if the power applied to winding is too high so that the normal vaporizing process is disturbed. On those areas the temperature increases further and hazardous substances, namely Acrolein and Formaldehyde can be generated. Note, that the amount of these substances generated is much less than during smoking of a tobacco cigarette. Moreover the user will instantly stop vaping because of the bad taste.

Temperature Control

2.1 Advantages of temperature controlled vaping

a) **No hazardous substances**

With temperature controlled vaping, the electronic makes sure that the temperature of the heater winding stays within regions, where no hazardous substances are generated – no matter how dry the winding is. The customer doesn't have to care or control, whether the coil is wetted with liquid. This is a major convenience increase for vaping.

b) **Better Taste**

Depending on the specific temperature of the vape within the permitted range, the different flavors are tasted with different intensity. So by varying the temperature the taste will be influenced. Without temperature control the vape is a not well defined mixtures of flavors. It is similar to the taste of a wine, which also varies with different temperatures. If it is too cold merely the different flavors can be tasted, if it is too warm, the different flavors get flat and alcohol taste dominates.

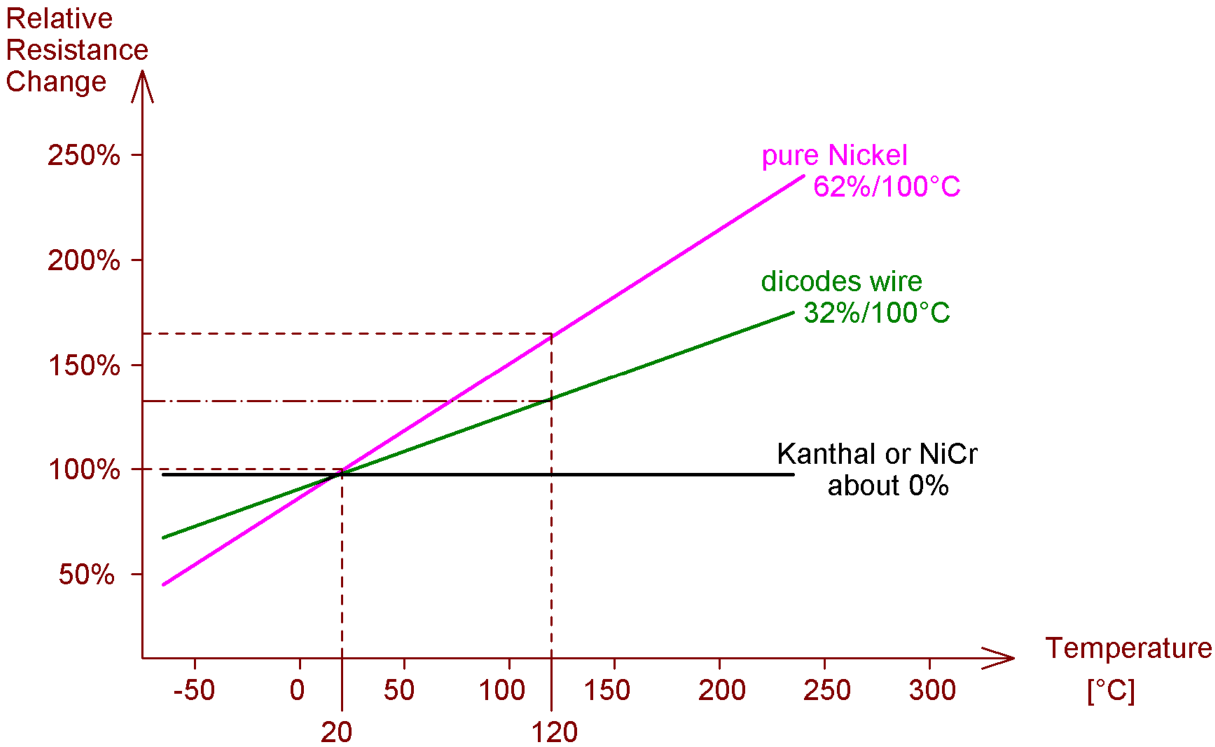
c) **Battery life**

Once the coil is hot, the energy needed to keep it hot is much smaller than the energy needed to heat it up. Depending on the individual coil built, the user can expect a 1.5 times longer battery life.

Operation principle

In order to enable temperature controlled vaping, first of all the heater winding's temperature has to be measured. As it is impossible to have additional electrical contacts for separate temperature sensors with standard 5-10 threads and the construction of all currently available atomizers , the temperature needs to measured using the heater-wire itself.
Therefore it is mandatory to use a wire, which has a distinct temperature coefficient of its resistance. The electrical temperature coefficient describes the change of resistance in dependence of a temperature change.

As an example: The resistance of a pure Nickel wire changes by 62% when the temperature increases by 100°C. The picture below shows this. Note, that the change is not completely linear, but a curve. But this can be neglected here.



In contrast, on standard mods without temperature control, the wire is chosen to have no or very little temperature dependency, like Kanthal or NiCr.
In general we can state: The higher the wire's resistance temperature coefficient, the higher the accuracy of the temperature control.

With the dicodes 2380 and Dani Extreme V2, wires with a coefficient between 10% per 100°C and 65% per 100°C can be used, which covers the range starting with stainless steel wire, Titan wire, dicodes wire, up to Nickel wire.
(The coefficient can be adjusted using a dedicated menu item in the extended functions menu.)

Unfortunately, often wires with a high coefficient, like Nickel, have very good electrical conductivity and therefore have several drawbacks in their usage:
- With a normal length windings (coils), the resistance will be very low (<0.2 Ohm). This induces high operation currents and thus reducing the overall efficiency (battery discharge time) and increasing the susceptibility to contact resistances to the atomizer and other contacts in the system.

- With a bigger and longer wire to achieve a higher resistance, much more energy is needed (thermal mass) to heat up the atomizer quickly, or the vaping will be delayed a lot.
- Using a thinner wire reduces the currents, but the mechanical built of the winding is more difficult, the total heat-delivering surface of the wire is small and the danger of hot spots is increased.

Summarized: The usage of high temperature coefficient wires has several disadvantages.

Wires made of metal alloys can be composed to have a high specific resistance (low electrical conductivity) while still having a measureable temperature coefficient. For example stainless steel wire has a coefficient of about 10.5%/100°C (note that different stainless steels may have varying coefficients). A major advantage is that the handling is much easier, as it has a good mechanical stability, and that the winding has low thermal mass but a big vape generating surface.
Of course the lower temperature coefficient results in smaller absolute temperature measurement accuracy. For example, using Nickel wire, the temperature can be measured to about 5°C accuracy, whereas the stainless steel wire, the initial absolute accuracy is just 30°C. This seems to be quite poor but the relative <u>repeated accuracy is much better</u>. I.e. once an optimal temperature for the best taste of a specific liquid is found (by iterative playing around with the setting) the adjusted temperature can be kept all the time. Important is to follow the recommendations below.

To enable an accurate temperature measurement, an extremely precise resistance measurement is mandatory. The dicodes electronic is able to measure the resistance to an accuracy of 1mOhm (1/1000 of an Ohm).

There is additional explanatory need: The electronic not only measures the heater-winding, but the resistance of the whole atomizer built including all contact resistances, mainly the (screw-) fixation of the wire and the 5-10 thread.
The thermal coefficients of those contact resistances are dramatically different to the one of the wire. Moreover little changes in the mechanical arrangement, e.g. the subsequent fastening of the atomizer, or thermal bracing, which are created by the heating, can easily create changes of the resistance of several mOhms (milli-Ohms, 1/1000 Ohm).
Exemplification:
Assume a stainless steel heater wire has 0.1 Ohm of resistance at 20°C. With the coefficient of 10%/100°, a measured change of 1mOhm would mean a 10°C temperature change!
If the atomizer was fastened again or due to thermal bracing, the resulting resistance change of for example 10mOhms, increase the measurement error to 100°C.
In contrast, if we used a Nickel wire with 0.1Ohm, a resistance change of 10mOhm translate into an error of just 16°C.
As the Nickel wire has much higher conductivity, a usable heater winding will have between

0.1 to 0.2 Ohms, whereas a stainless steel wire should have between 1 and 2 Ohms when using temperature controlled vaping.
(We recommend to use the dicodes wire, with a temperature coefficient of 32%/100° and a resistance between 0.5 and 1.5 Ohms. This wire provides an optimal compromise between temperature accuracy, thermal mass and vape generating surface.)

⇨ Independent of the type of wire, it is always possible to generate an excellent vaping taste, but the user must be aware of the problems related to contact resistances, especially with very low ohmic coils.

Due to the warming up of the vaporizer and head, it is advantageous to have a spring element between atomizer and mod, to compensate the danger of changing contact resistances. If neither the mod nor the atomizer has a spring contact, it is better to have the mechanical stop provided by the contact pin and not by the head. In other words electrically it is better to accept a gap between atomizer and head as otherwise the resistance is somewhat undefined.

Initiating the temperature controlled operation
The temperature control is prepared by an initial reference measurement of the coil at room temperature of 20°.
Note: On the dicodes Mods the reference measurement can be selected to be performed automatically after each power up or when the atomizer is replaced or by a manually initiated measurement (preference is set in the extended functions menu).
After the reference measurement, a later fastening or moving of the atomizer should be strictly avoided. If the mechanical change is necessary, a new reference measurement is recommended. Therefore the user just has to wait for the atomizer to cool down and then choose the reference measurement in the menu, otherwise the temperature cannot be identified correctly.

Background Information referring to the reference measurement
To enable the temperature control, the mod initially needs to measure the resistance of the coil at a known temperature. For this purpose it does the reference measurement. All later calculations and temperature display depend on the correctness of this measurement.

At this point the mod assumes that the atomizer has a temperature of 20°C. In case that the atomizer is still warm, due to vaping before, the user should wait, until the atomizer has cooled down. In case that the ambient temperature is not around 20°C, the temperature settings should be adjusted by an offset accordingly.
Example: Ambient is 40°C => adjust the temperature to 20° less, e.g. 180°C instead of 200°C

In case the user wants to repeat the reference measurement, the mod should be switched off followed by waiting until the atomizer has cooled down and then switch on again. Another option is to manually initiate the referencing by choosing the menu item.

Procedure to build a coil for temperature controlled vaping

1. Create coil and connect to atomizer with good contacting
2. Do not insert the wick (oxidized metal mesh is OK)
3. Apply atomizer to mod
4. Set Heater Control to 0 (Standard or normal mode)
5. Power up coil until it glows
   Remark: By letting the coil glow, mechanical bracing is compensated and contact resistances settle and don't drift much later. Also, the coil is oxidized, reducing the danger of shorts. If there are windings on the coil which glow brighter than others, the mechanical arrangement should be adjusted. Possible shorts between windings must be avoided, because this will degrade the temperature control drastically as the resistance jumps all of a sudden. Because of possible shorts, micro-coils are not recommended.
6. After the glowing, insert the wick. Apply liquid to the coil and wick. Check for shorts between windings.
7. Program the correct wire temperature coefficient !!!
8. Activate temperature contolled vaping by setting Heater Control HCtrl=1

Now start vaping and adjust the power and temperature iteratively, until you get the best taste and result. Note that in general short coils with thin wire have a small thermal mass and a smaller surface. They should not have initial high power levels applied, because the danger of hot spots is higher. Hot spots lead to bad taste, which is an indicator of hazardous substances. If you want a lot of vape, use a thicker wire and higher power setting.

Note: The power setting with temperature control enabled, defines the maximum power that the temperature control algorithm may apply to the coil. This is only relevant during the heating up phase at the beginning of a puff until the temperature has reached the setpoint.

The picture below shows a comparison between a vape-puff with and without temperature control. The graph for non-temperature controlled mode shows an initial power boost function (not all mods have this functionality). Otherwise the heating up would be much slower compared to the temperature controlled mode.

So both modes show a quick coil heatup, but with constant power applied to the coil, the temperature increases all the time until a value is reached where the rate of liquid flow cooling the coil and the power come to equilibrium. But then the temperature might already have reached regions where hazardous substances are generated.
With temperature control enabled, the electronics keeps it at the pre-set value, without the danger of creating hazardous substances.
What also can be seen is that the average power for keeping the coil hot is much lower than the initial boost power – the picture is not a measurement curve of course, but illustrates the situation pretty good, nevertheless. Generally speaking: The power needed during temperature controlled vaping is low.