

Letter to the Editor

Exhaled Breath Temperature Measurement Made Easy

Editor,

We read with utmost attention and maximal strain of our mathematical faculties the article by Pifferi et al. (1). They demonstrate in a convincing way that it is the mean value of temperature at the plateau of exhalation (mvPLET), rather than the rate of temperature increase ($\Delta^\circ\text{eT}$) as suggested by Paredi et al. (2), which differentiates asthmatic from non-asthmatic children. They had to utilize pattern recognition analysis of the recordings of the fast reacting thermocouple to account for the broom of the individual breath curves. The results by both principal component analysis and artificial neural networks reinforce their previous conviction that the measurement of PLET gave more reproducible within-subject inter-assay results than $\Delta^\circ\text{eT}$, and that PLET, but not $\Delta^\circ\text{eT}$, was significantly different between asthmatics and healthy controls (3).

We would like to lend our support to the above findings and conclusions by sharing our experience with a somewhat different approach in exhaled breath temperature measurement. Over the past years we have developed a small, potentially individual device, which accumulates the thermal energy released during expiration in an isolated chamber with a thermal block inside (4). The thermal block has high thermal capacity and excellent heat conducting properties. When the exhaled breath gets in the device, it overflows the thermal block and fills the chamber. The inflow opening is with a reversion valve which closes the chamber during inhalation. Thus the last portion of exhaled air, which has stayed longest in the lungs, remains in the chamber and imparts its temperature to the thermal block. The superfluous air comes out through outflow openings. The temperature of the thermal block is assessed by a high precision thermal sensor (discriminative ability $< 0.03^\circ\text{C}$). The measurement continues until no further increment is noted. The device can be used in adults and children, and the data we have gathered show

that exhaled breath temperature measurement distinguishes between asthmatics and non-asthmatics, and also picks up changes due to anti-inflammatory treatment or to exacerbations.

We also developed a mathematical model, which we are now using for analysis of the exhaled breath temperature during the measurements, in an attempt to build a user-friendly piece of equipment, which reliably prompts by an audio signal that the end of the test has been reached. This mathematical model depicts the registered incremental temperature curve in relation to the initial temperature of the air in the thermal chamber, predicting the reach of the temperature plateau with an error $< 2\%$.

Briefly, we also have an exponential curve, which is however different from the single temperature curve analyzed by Pifferi et al., as it is the cumulative result of multiple exhalations, heating the thermal block to an infinite maximum. This curve depends on two primary elements: (i) energy storage/thermal capacitance, and (ii) energy dissipation/thermal resistance. We describe the exhaled breath temperature using a first order system response:

$$y(t) = y_\infty + (y_0 - y_\infty)e^{-t/T},$$

where T is the time constant, y_0 is the initial temperature at time (t) $t = 0$, y_∞ is the predicted final temperature ($\infty = \text{infinity}$), e is natural logarithm.

The exponential response curve $c(t)$, relevant for our method of measurement, is shown in Fig. 1. There it is parceled into time constants (T). In the first time constant of the exponential curve, the temperature goes through changes from 0% to 63.2% of the final value. In the second time constants ($2T$), the response reaches 86.5% of the final value. At $t = 3T$, $4T$ and $5T$ the response reaches 95%, 98.2% and 99.3% respectively of the final value. Thus, for $t > 4T$, the response settles within 2% of the final value.

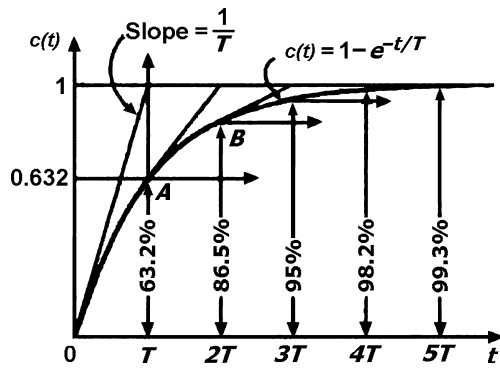


Fig. 1. Exponential response curve $[c(t)]$ relevant to the method of Popov et al. (4) (see explanations in text).

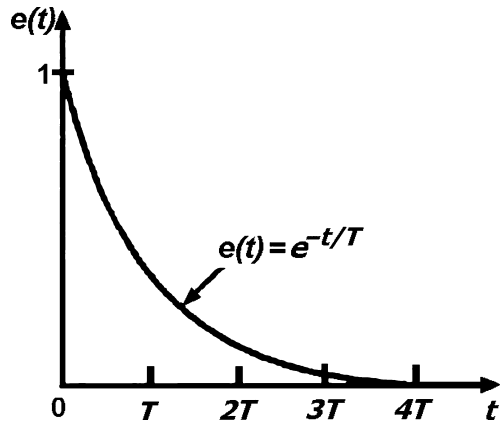


Fig. 2. Error $[e(t)]$ associated with the mathematical model.

As seen from Fig. 1, the steady-state is reached only after an infinite time. In practice, however, a reasonable estimate of the setting time is the length of time the response curve needs to reach within the 2% line of the final value, i.e. four time constants.

The error associated with the mathematical model $[e(t)]$ has a reverse exponential shape (Fig. 2). It can be seen that at $4T$ it is minimal.

This mathematical model has the important advantage that it overcomes the problems associated with blowing pattern of the subjects and the initial temperature of the device, which are difficult to regulate. On its basis we have

constructed our algorithm, which eliminates the chances of 'premature detection' of a plateau and improves the repeatability of temperature measurement, as it has a consistent starting point ensuing from the computed time constant T . It takes into consideration the characteristics of the exhaled breath temperature and the blowing pattern of the user by means of a first order system, computes the time constant T and uses it to predict the time taken for temperature stabilization (multiples of the time constants). This allows searching for stable temperature by using the predicted stabilization time as a guide to establish the region of search. By applying a moving average envelope detector (low pass filter), the region of possible stable temperature (the plateau) is identified. An important result of this approach is shortening of the measurement to a minimum (< 3 min), which is of particular importance when working with children.

We do hope that this additional information may widen the perspective for the use of exhaled breath temperature measurement in airway inflammation research and bring it further to routine clinical practice.

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