THE TEMPERATURE RESPONSE OF MAMMALS TO A STEP CHANGE OF THE EXTERNAL TEMPERATURE

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Abstract
Our paper deals with the description of reaction of warm-blooded animals to changes in temperature. A complex regulation mechanism is started during the changes in temperature, which is aimed at stabilisation of the basal temperature of an animal. This process is called PID controller. The process leads to gradual changes in the surface temperature of an animal. The course of changes in temperature over time is recorded during the experiments described below. During certain amount of time, which is introduced here as the relaxation time, changes in temperature end almost entirely. The change in temperature of a certain part of an animal body is determined by each animal. The time which is needed to this change in temperature is also determined. As it become apparent, both these figures depend on animal species and also on the size and the sign of change in the external temperature. So the paper shows the methodology for data, which describes the thermoregulatory process. The experiment was executed on a llama of Vicugna pacos – alpaca and on a sheep of Clun Forest. By comparing the results of the experiment for the animals mentioned above we came to the clear conclusion. The speed of thermoregulation of the measured llama is much higher than the speed of thermoregulation of the measured sheep.

Key words: thermoregulation, warm blooded animals, PID controller, relaxation time.

INTRODUCTION
The thermoregulation of the warm blooded animals, which stabilises the basal temperature, is a very complex process. The thermoregulation consists of chemical as well as mechanical actions, which are directed by nervous and lymphatic systems. In the long-term changes are involved also hormones. It seems that during the short-term changes, the temperature of the peripheral parts of a body is regulated primarily mechanically. We will show one example. When the information about hypothermia of a certain peripheral part of a body below critical temperature t_c = 21.3 °C reaches the brain, the flow of blood through this limb is stopped almost immediately. It is the consequence of the constriction of the blood vessels. From this moment on, no blood flows into the limb and for this reason no heat is brought there and also no new substances (ATP) from which the heat can be created. The limb becomes insensitive without inflow of blood, because tactile cells do not have required energy and oxygen, which are needed to the creation of a neural excitation. The same applies to the activity of the muscular and temperature sensory cells. The movement of the hypothermic parts of limbs is possible only in a passive way, e. g. by pulling tendons, which originates outside the hypothermic parts of the body. After the warming of the hypothermic part of a limb with the help of external heat, the blood vessels dilate again. The “warm” blood flows into the limb rapidly. At the same time, the cold blood is ejected out of the limb into the body, which may cause a thermal shock. In any case, it leads to the rapid decrease in temperature. It is obvious, that the description of such complicated process is very difficult with using only few parameters. For that reason, we concentrated on the purely phenomenological description of changes in the external temperature of the limb. Our aim in this phase of the research was to compile a sufficiently general mathematical description, which characterizes the temperature reaction of animal to a step change of the external temperature with the help of several parameters. In accord with the description of the activity of PID controller, we are introducing only two parameters which primarily describe its features. The introduction following two parameters is expedient and for basic description sufficient. 1. The finite change of the temperature in the infinite time, which takes place on the surface of the limb, during a step change of the external temperature by 10 °C. The temperature change over time takes place approximately exponentially. Therefore we used the power coefficient of this exponential curve as the second parameter, which describes the thermoregulatory process, which is caused by the temperature jump of the surroundings.

MATERIALS AND METHODS

The temperature of the animal was stabilised in a lee outdoor enclosure during several hours. After that the surface temperature of the animal was measured by a thermographic camera (We used the camera TiR-01 the Fluke brand.). In the case of examination of the furred parts of an animals body, it was necessary to pull fur apart in order the skin could be seen. The animal was brought into the heated stable after taking a picture. The current temperature was measured by using a thermographic camera always at the same spot on the surface of the animal. Taking pictures was carried out by using software Smart View 3.0 periodically every 30 seconds. The measurement was ended after stabilization of body temperature of the animal. The animal stayed in the heated stable five hours and then was brought in the lee outdoor enclosure again. Here, other measurement was carried out by the same procedure.

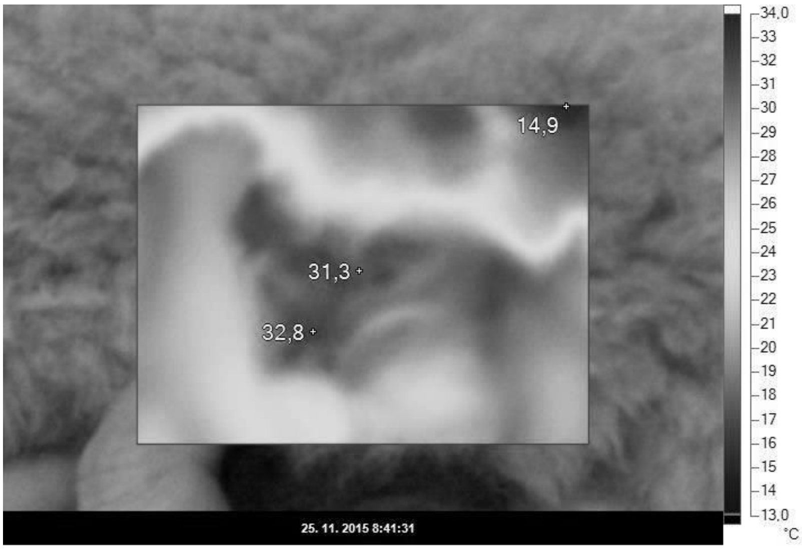

Fig. 1. – Llama after the transition from the outdoor enclosure to the stable

For the sake of completeness, we had to determine the temperature and the humidity of the surroundings, both in the cold and in the warm zone. It was done by using anemometer Testo 410-2. The time series of the temperatures was fitted with the suitable exponential curve with using the least squares method. We have used the Solver tool of the program MS Excel 2010 for this purpose – see MOŠNA (2010). In this way the following parameters were ascertained: the temperature change Δt and the relaxation time τ. The calculation was made as follows. We calculated the functional values for the functions (1) and (2) in the times of measurements, which were exactly deducted from the dating of the respective image.

$$\zeta(t) = \zeta_1 + |\Delta\zeta_1| e^{-\frac{t}{\tau_1}}, \quad (1)$$

$\zeta(t)$ – the approximated temperature of the limb of the animal,

ζ_1 – the initial value of the temperature of the animal at the start of the increase of temperature,

$\Delta\zeta_1$ – the temperature difference, of which increases the temperature of the animal during the measurement,

t – the time,

τ_1 – the relaxation time of the temperature increase.

$$\zeta(t) = \zeta_2 - |\Delta\zeta_2| e^{-\frac{t}{\tau_2}}, \quad (2)$$

$\zeta(t)$ – the approximated temperature of the limb of the animal,

ζ_2 – the initial value of the temperature of the animal at the start of the decrease of temperature,

$\Delta\zeta_2$ – the temperature difference, of which decreases the temperature of the animal during the measurement,

t – the time,

τ_2 – the relaxation time of the temperature decrease.

We calculated the sum of squared differences of the measured and the approximated values. We found the coefficients ζ_i, $\Delta\zeta_i$ and τ_i. with the Solver tool. The coefficients of such values, for which the sum of squared differences is minimal. We calculated the mean square deviation for $\Delta\zeta_i$ coefficients using the relationship (3).

$$s(i) = \sqrt{\frac{\sum_{j=1}^{N}\left(\zeta_i(j) - \zeta_i'(j)\right)^2}{N(N-1)}}\ , \qquad (3)$$

$s(i)$ – the mean square deviation for the increase or the decrease of temperature,

$\zeta_i(j)$ – the approximated temperature in time j,

$\zeta_i'(j)$ – the measured temperature in time j,

N – the number of measurement.

There is a connection between the coefficient of the temperature reaction of the animal and the temperature change of the surroundings. Therefore we introduced the relative temperature coefficient by relationship (4), which specifies the animal.

$$\alpha_i = \frac{\Delta\zeta_i}{\zeta_1^a - \zeta_2^a}\ , \qquad (4)$$

ζ_1^a – the air temperature before measurement,

ζ_2^a – the air temperature during measurement.

To verify the functionality of the method, we tested animals of llama and sheep. They were adults in both cases.

RESULTS

The conditions of the measurement are stated in the Tab. 1. The determined values of the coefficients of the equations (1) and (2) are shown in the Tab. 2.

Tab. 1. – The conditions of the measurement

Measured animal	Llama		Sheep	
i	1	2	1	2
ζ_i^a (°C)	15.2	1.9	14.9	2.3
Air humidity (%)	42.2	74.3	50.2	76.4
Wind speed (m/s)	0	1.6	0	1.8

Tab. 2. – The determined values of the coefficients of the equations (1) and (2)

Measured animal	Llama		Sheep	
i	1	2	1	2
ζ_i (°C)	31.2	32.3	33.1	34.8
$\Delta\zeta_i$ (°C)	4.4	-3.1	5.6	-1.7
α_i	0.33	-0.23	0.44	-0.13
τ (min)	7.5	6.1	18.7	12.8

The measured temperature dependences and their approximation by the equations (1) and (2) are stated in the Fig. 2 – 5.

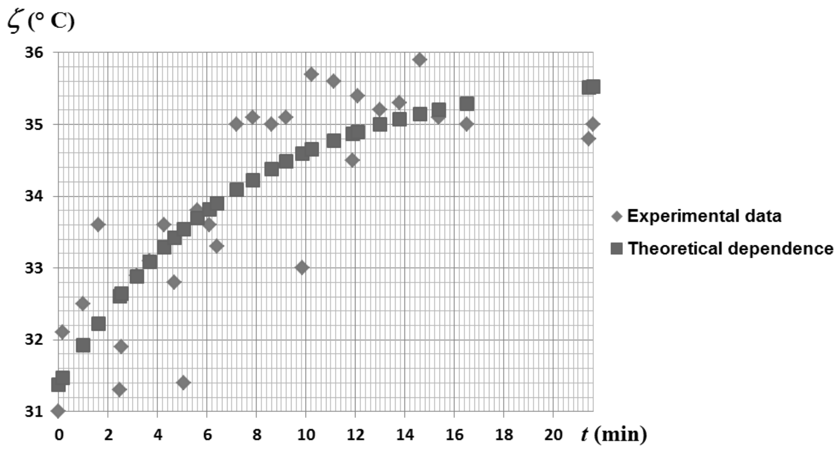

Fig. 2. – The increase of the body temperature of llama after the transfer out of the outdoor enclosure into the heated stable

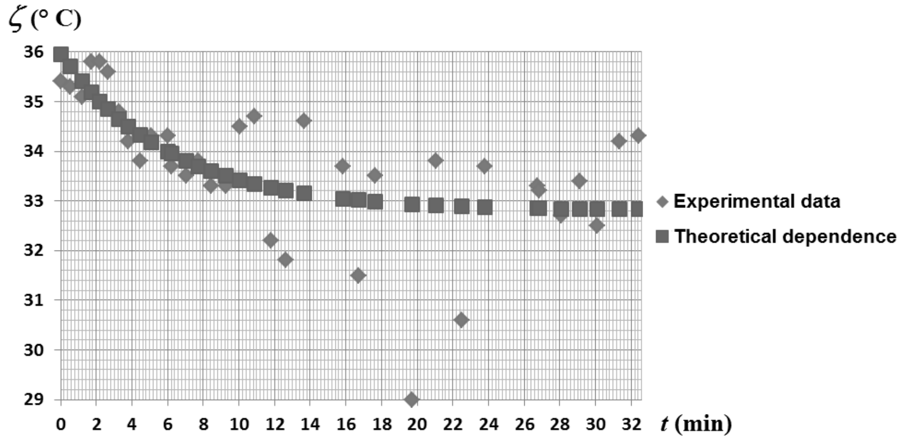

Fig. 3. – The decrease of the body temperature of llama after the transfer out of the heated stable into the outdoor enclosure

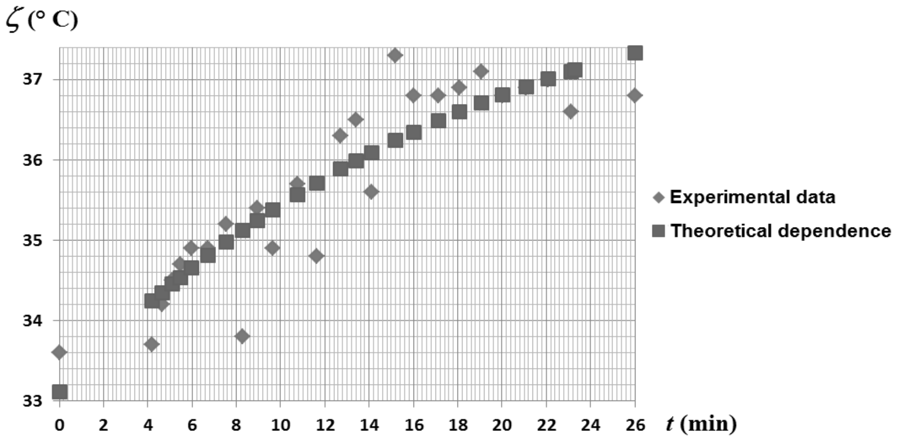

Fig. 4. – The increase of the body temperature of sheep after the transfer out of the outdoor enclosure into the heated stable

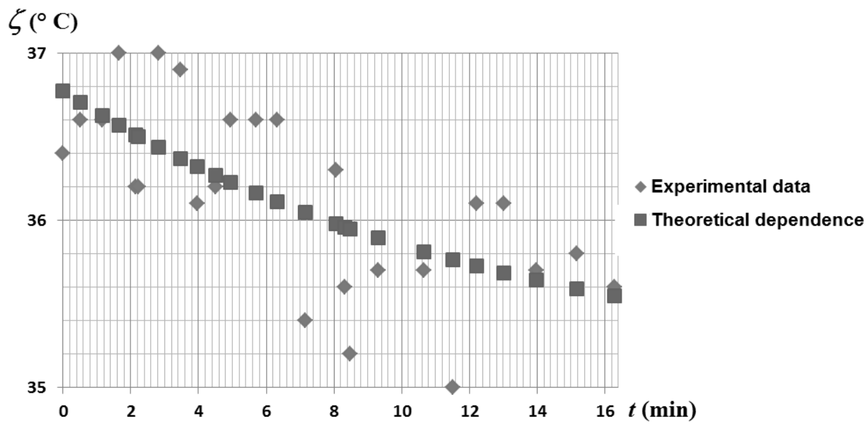

Fig. 5. – The decrease of the body temperature of sheep after the transfer out of the heated stable into the outdoor enclosure

DISCUSSION

Fig. 1 – 5 confirm our assumption that the basic features of the temperature changes of the animal in response to a step change in the external temperature can be broadly characterized by equations (1) and (2). Thus proving that the temperature differences $\Delta\zeta_i$ and the relaxation times τ, whose real values are shown in the Tab. 2, are suitable characteristics of the temperature reaction of the animals. The variance of measured

values for the increase of temperature (see Fig. 2 and 4) is always smaller than for the decrease of temperature (see Fig. 3 and 5). Determined parameters in Tab. 2 show that their values differ for different kinds of animals significantly and therefore they fulfill the necessary condition of the applicability of the proposed method. (i.e. the ability to distinguish between two different objects using obtained parameters.)

CONCLUSIONS

We managed to establish a methodology for the determination of basic thermoregulatory parameters of animals. We have verified that the data obtained as described above are applicable to our way of evaluation and determination of parameters: temperature difference $\Delta\zeta_i$ and relaxation times τ_i for the increase and the decrease of temperature. The measurements were executed for both of these processes on a llama of Vicugna pacos – alpaca and on a sheep of Clun Forest. We determined for these animals: Relaxation times are in llama 7.5 minutes and in sheep 18.5 minutes, for the positive change of the temperature (i.e. transition from cold place to warm place). Relaxation times are in llama 6.1 minutes and in sheep 12.8 minutes, for the negative change of the temperature (i.e. transition from warm place to cold place). During a step change of the external temperature by 10 °C, we observed the following facts. The temperature changes of the peripheral parts of a body are in llama 4.4 °C and in sheep 5.6 °C, for the positive change of the temperature. The temperature changes of the peripheral parts of a body are in llama 3.1 °C and in sheep 1.7 °C, for the negative change of the temperature. The relative temperature coefficients for our llama are: 0.33 – in the case of the temperature increase and -0.23 – in the case of the temperature decrease. The relative temperature coefficients for our sheep are: 0.44 – in the case of the temperature increase and -0.13 – in the case of the temperature decrease. We see the causes of differences of thermoregulation between both animals in these facts: 1) The larger percentage of the subcutaneous fat of sheep. 2) The dissimilarity of environment, where both animals usually live. The environment, where llama usually lives, is typically colder; with more pronounced temperature fluctuations, which requires to respond faster. Regarding the dissimilarity of the fur quality of both animals, it is a fact, that the llama fur isolates better than the sheep fur. This reduces the speed of the llama thermoregulation somewhat. It means, if llama had the same fur like a sheep, the relaxation time of llama would be even lower, than we measured in our experiment.

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