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# EXPERIMENTAL TESTING OF TOBACCO SELF-IGNITION TEMPERATURE

**Abstract:** *Fires caused by spontaneous ignition represent a serious occupational and environmental hazard. The process of tobacco self-ignition is slow but it results in tobacco combustion that is hard to extinguish, causing loss and other harmful effects. This is what motivated us to conduct research on the causes and mechanisms of this phenomenon. The results obtained depend on the methods and equipment used. This paper describes the procedure to specify specimen temperature versus ambient temperature on the basis of time. The equipment used and the measuring process are also described in the paper. We concluded that the values of self-ignition temperature are not laboratory constants for certain species of tobacco but variables, which primarily depend on the temperature of the working environment. The data we obtained in the experiment was used to train an RBF (Radial Basis Function) network. After training, the RBF network was able to predict self-ignition temperature for some cases of working environment temperatures that were not considered.*

**Key words:** self-ignition, experiment, tobacco samples.

## 1. INTRODUCTION

Since recently, the attest of exported or imported products worldwide includes the temperature of self-ignition, as an important characteristic of a product. For safety reasons, this property is of great importance when tobacco is stored, transported, or technologically treated.

Tobacco storage in warehouses has always been a problem because of the fact that spontaneous heating of the mass sometimes occurs in warehouses.

It is well-known that the quality of cigarettes produced from tobacco that had been heated will be far worse than from regular tobacco. Spontaneous heating does not always have to cause self-ignition of tobacco, but can result in poor quality of the tobacco, making it unusable for the manufacture of final products.

The process of spontaneous heating may eventually lead to self-ignition.

Based on literature sources, we can conclude that there are several ways in which the process of spontaneous heating of tobacco may occur while it is stored in a warehouse.

First, it is possible that microorganisms, usually mold, have developed on the tobacco. This process is conditioned by the amount of water content in the system; the greater the water content, the more probable the development of microorganisms. During their development, microorganisms release heat in the tobacco mass and this heat is slowly taken out of the mass and retained in the system, leading to gradual heating of the mass to 60-65°C, when microorganisms die.

The second possibility of a heat-releasing process is oxidation of unsaturated compounds present in tobacco, with oxygen from the air or water from the tobacco.

Spontaneous heating of a mass is a phenomenon in which there is an increase in temperature from within and not from the surrounding.

All processes of self-ignition have the same time diagram. In the initial phase of the process, reactions occur slowly and temperature also increases slowly. The process begins to accelerate when it reaches a certain temperature, and the diagram shows that the temperature change of the mass exceeds the temperature of self-ignition of a material in a system, which leads to smoldering or classical ignition.

The time from the beginning of temperature increase to the temperature level of self-ignition is the induction period, and this is the period when harmful consequences should be prevented. It can last from several hours to several months.

Since the harmful consequences are obvious, the authors propose a methodology and the apparatus for testing the process of tobacco self-ignition.

## Experimental testing of the process of self-ignition of tobacco layers

Literature offers some methods and apparatuses to test self-ignition. The authors designed the experimental apparatus based on analyses of a number of different apparatuses found in literature, ensuring that the working conditions are similar to those in actual warehouses.

The apparatus is designed to contain a heating chamber with radiation and low convection.

The experimental apparatus consists of:

- the experimental chamber;
- the system for temperature regulation;
- the system for measuring the working environment and sample temperature; and
- the sample holder.

The block diagram of the experimental setup is shown in figure 1.

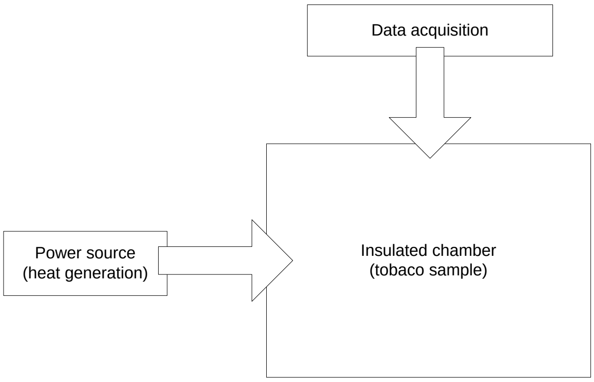


**Figure 1.** *Block diagram of the experimental setup for testing tobacco self-ignition*

The main part of experimental setup is the insulated chamber equipped with thermocouples for measuring ambient and sample temperatures, the sample holder, the chamber heater, the insulated chamber door, and the chimney. The external modules are the power source module and the data acquisition module.

The insulated chamber is actually a dryer with a volume of 0.02 $m^3$. The chamber has the ability to control the temperature from 100°C to 300°C, which can be maintained constant with an accuracy of ±1°C. At the top of the dryer there is a 2 cm vent. The sample should be placed at half the height of the chamber space. We used an insulated thermocouple (Chromel/Alumel) to measure the temperature of the sample.

The sample is formed in a cylindrical vessel, with the dimensions d=40 mm, and H=50 mm, made of fine wire mesh, with a diameter smaller than the smallest examined granulation. The container manages the tobacco and tobacco dust that we have to examine ("dry in air"). A sample thus prepared is then exposed to elevated temperature ranges of 100-300°C and the temperature change in the sample is recorded.

The duration of the experiment amounted to 3 hours, since the previously performed experiments showed that it is a sufficiently long period of time to ascertain whether self-ignition can occur in the sample tested at specific conditions, as well as to establish the point of self-ignition.

The main principle of experimental research is the monitoring of the temperature change in a tested tobacco layer sample.

For the experiment, the sample is placed into the experimental chamber, which has already been heated to a certain temperature. The process of heating, the phenomenon of self-heating, and self-ignition are registered by means of thermocouples.

Definitions of self-ignition temperatures vary in literature, but all of them agree on the notion that the temperature of self-ignition is the lowest temperature of experimental material, at which self-heating causes a sudden increase of reaction speed accompanied by a release of heat. This is the temperature of experimental material at which tobacco temperature suddenly increases after a time period called the period of induction. Self-ignition temperature is the lowest temperature in the sample that is high enough to cause self-ignition.

Possible tobacco layer samples affect the shape of the sample holder, which works with layers of different thickness.

In every conducted experiment, the inclination towards self-ignition is determined either by the slow increase in the temperature of the working environment or by placement of the sample in an enclosed heat source for a certain time period.

In this paper, we opted for the latter research method because it is a relatively simple method that yields acceptable results.

In all the existing methods, the temperature of self-ignition is required, but the proposed method indirectly involves the temperature of the working environment, which causes self-ignition after a certain time period. The focus is on this temperature because, under working conditions, it is the only parameter that can be controlled and manipulated easily. We could say that temperature change is one of the possible parameters that are supposed to say whether self-ignition will occur under given conditions.

In the analyses performed until today, the following factors influencing self-ignition of tobacco have been registered:

- the system for temperature regulation;
- temperature of the working environment;
- thickness and shape of tested tobacco layer;
- chemical structure of tobacco.

The conducted experimental research yields data on the temperature change of the sample over time for a given temperature of the working environment.

The diagram of temperature change over time is given in figure 2, on the basis of experimental data. The use of neural network in the treatment of experimental data is warranted due to its ability to approximate nonlinear mapping.

Figure 2 represents a three-dimensional diagram with three independent variables: τ - time of tobacco sample exposure to the ambient temperature, t' - ambient temperature, and t - tobacco sample temperature.

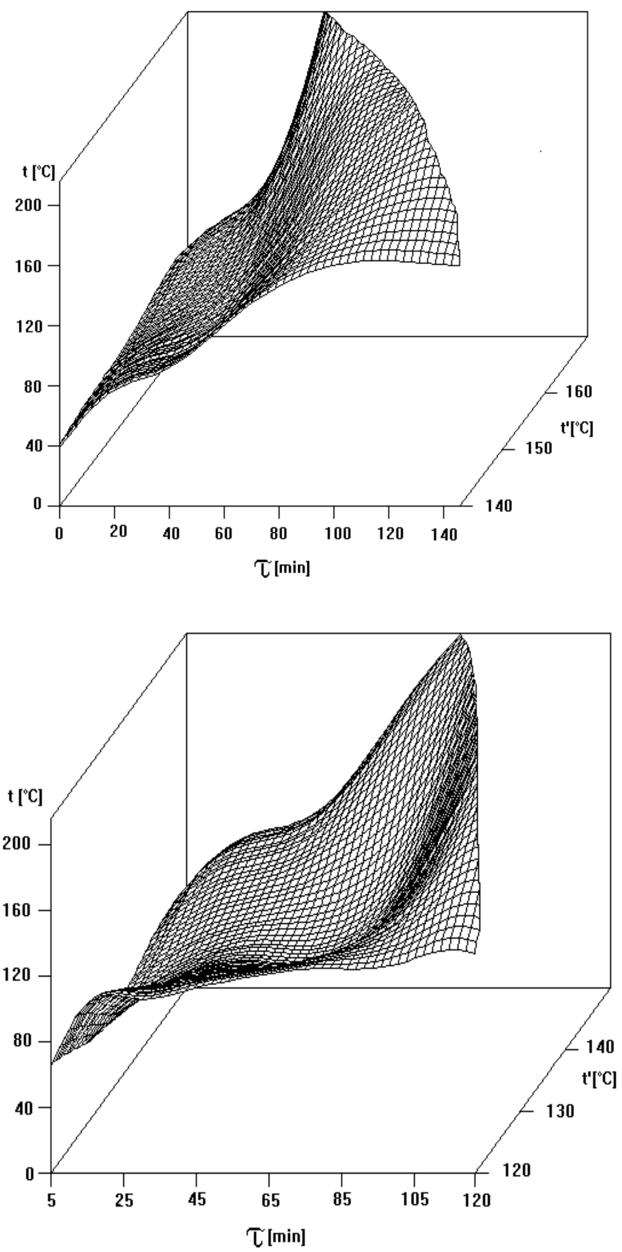


**Figure 2.** *Approximation of tobacco samples temperature dependence on ambient temperature over time*

In this paper Radial basis function network (RBF network) is applied to functional approximation problem.

Like neural network with sigmoidal nonlinearities, RBF networks have the capability to represent arbitrary function but they can be trained more rapidly [4,5].

The networks we shall discuss have two linear inputs and none linear output unit (in genera RBF network can have n input units and p output units). The internal units are a single layer of m receptive fields which can give localized response function in the input space. The overall response function of the network is:

$$f_k(\vec{x}) = \sum_{i=1}^{m} w_{ki} g_i(\vec{x}), \; k = 1,\dots, p$$

$$g_i(\vec{x}) = \exp\left( -\sum_{j=1}^{n} \left( \frac{x_j - m_{ij}}{\sigma_{ij}} \right)^2 \right)$$

Here, $\vec{x} = \left[x_1,\dots,x_n\right]^T$ is real-valued vector in input space, $g_i$ is i-th receptive field response function ( is gaussian in our case). Parameter $w_{ki}$ is function value associated with each receptive field; $m_{ij}$ and $\sigma_{ij}$ are the center and width of the i-th receptive field for j-th input.

The purpose of learning algorithm is to tune the parameters $w_{ki}$, $m_{ij}$ and $\sigma_{ij}$, in order to minimize the quadratic error defined as:

$$E = \frac{1}{2}\sum_{\lambda}^{\Lambda}\sum_{k=1}^{p}\left( f_k^{\lambda}(\vec{x}) - f_k^{*,\lambda}\right)^2,$$

where $\Lambda$ is number of training samples, $S_p^{\lambda} = \left(x_1^{\lambda},\dots,x_n^{\lambda}; f_1^{*,\lambda},\dots, f_p^{*,\lambda}\right)$ is λ-th training sample ($x_1^{\lambda},\dots,x_n^{\lambda}$ is training sample input and $f_1^{*,\lambda},\dots, f_p^{*,\lambda}$ is training sample output). In our case training set consist of samples $(\tau, t'; t)$ where $\tau$ is time of exposing a coal sample to the ambient temperature, $t'$ is measured ambient temperature and t is measured temperature of coal sample.

The Gradient Descent method consists in applying the following formulae:

$$w_{ki}(l+1) = w_{ki}(l) - \eta_w \frac{\partial E}{\partial w_{ki}},$$

$$m_{ij}(l+1) = m_{ij}(l) - \eta_m \frac{\partial E}{\partial m_{ij}},$$

$$\sigma_{ij}(l+1) = \sigma_{ij}(l+1) - \eta_w \frac{\partial E}{\partial \sigma_{ij}(l+1)},$$

where $\eta_w$, $\eta_m$, $\eta_\sigma$ are Gradient Descent speeds.

## CONCLUSION

Since every obtained temperature depends on the layer thickness and the type of sample, it can be concluded that the temperature is not a constant value for certain species of tobacco. Thus, it is possible to determine the tobacco sample temperature dependence on ambient temperature over time from a certain number of usual values that can be used for neural network training. In other words, we can predict the behavior of another (untested) tobacco sample, or layer thickness, or temperature of the working environment.

Using some of the mathematical predictive procedures, such as neural network, it is possible to predict and analyze the process of self-ignition and self-heating of tobacco in temperature periods in which no measuring was done.

The literature uses the definition of self-ignition temperature as the temperature at curve inflection point $(\tau, t)$, which is a necessary, but insufficient condition for the occurrence of combustion processes. The additional requirement would be as follows: the ignition ensues if the rate of temperature increase is greater than critical [ºC/min]. This additional criterion is proposed for the assessment of self-ignition.

While testing self-ignition, we gave special attention to the rate of temperature increase at the moment of passing through the operating ambient temperature $\upsilon=\Delta t/\Delta\tau$ [°C/min]. We discovered that there were occurrences of self-ignition in experiments in which the subject rate, called critical rate, was not under 1.29 [°C/min].

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## BIOGRAPHY

**Ljiljana Živković** was born in Vranje, Serbia, in 1949. She received the diploma in mechanical engineering, master and the Ph.D. degree in thermal science from the University of Nis, Faculty of Mechanical Engineering.
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# EXPERIMENTALNO ISPITIVANJE TEMPERATURA SAMOPALJENJA DUVANA

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**Nenad Živković, Emina Mihjalović**

**Apstrakt:** *Požari izazvani spontanim paljenjem predstavljaju ozbiljnu opasnost u radnoj i životnoj sredini. Proces samozapaljenja duvana je u osnovi polagan ali rezultira požarnim stanjem koga je teško ugasiti, pri čemu može doći do žrtava i materijalnih šteta. To je bio razlog što su autori sproveli istraživanje o uzrocima i mehanizmima ovog fenomena. Dobijeni rezultati zavise od metoda i opreme koja se koristi. Ovaj rad opisuje postupak određivanja temperature uzorka u odnosu na temperaturu okoline u funkciji vremena. Oprema koja se koristi u eksperimenu i postupak merenja su takođe opisani u radu . Zaključak je da vrednosti temperatura samozapaljenja duvana nisu laboratorijske konstante za pojedine vrste duvana, već promenljive veličine koje pre svega zavise od temperature okoline u kojoj se ispitivani uzorak nalazi. Podaci, dobijeni u eksperimentu su korišćeni za obučavanje RBF (Radial Basis Function) neronske mreže. Tako obučena RBF mreža je u stanju da predvidi temperature samozapaljenja duvana I za vrednosti temperature okoline koje nisu uzeti u obzir eksperimentom.*

**Ključne reči:** samopaljenje, eksperiment, uzorci duvana.