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Dynamics of temperature changes on the outer surface of Scots pine (*Pinus sylvestris* L.) cones exposed to microwave radiation

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Abstract: *Dynamics of temperature changes on the outer surface of Scots pine* (Pinus sylvestris L.) *cones exposed to microwave radiation.* In the article, the authors undertook an attempt to describe the dynamics of changes in the temperature of outer cone surfaces exposed to microwave radiation. Thermograms developed with a thermovision camera were used to analyse the process. Closed cones obtained from the seed cultivation tree stands in Grotniki Forest Inspectorate were used in the investigations. The cones were subjected to the influence of microwaves with the power of 800, 620, 440, 260 and 130 W until opening of the first husks on their surface was observed. The authors stated that the most suitable power level for the stage of preliminary reduction of water content in cones is the radiation power of 440 W. At that power, the time of impact of microwave radiation onto cones is equal to 30 s.

Key words: cone husking, heating, microwaves, thermogram

INTRODUCTION

Investigations related to forest management are conducted in several segments. Among them, of great importance are the investigations connected with machined obtaining of wood, both with the use of sawing machines [Wójcik and Petrów 2013] and multi-operation machines [Nurek 2013]. Analyses related to forest cultivation are equally important, with the seed husking process constituting an important section thereof. The process consists in drying of cones, which results in opening of their husks, thus making it easier to obtain the seeds.

Electromagnetic and microwave radiation is becoming increasingly important in current investigations into enhancement of crops, plant growth stimulation [Inozemcev 2013] and fructification. The application of microwaves characterised with the frequency of from 0.3 to 300 GHz and wavelength of from 1 to 0.001 m in drying processes is well known and practised in industry and science [Januszajtis 1991]. Thanks to microwaves – reflected by metal, but penetrating through glass, paper and most plastics – the material can be heated up quickly. Heating takes place as a result of intensive movements (vibrations) of water particles, which cause development of heat while hitting one another. Among others, this phenomenon is used in microwave ovens, in which the magnetron produces waves with the frequency of 2.4 GHz. Microwaves are also used for sterilisation of utensils in medicine [Kukawska 1996, Kędzia 1998], in the wood industry – for disinfestation and disinfection of wood [Krajeński 2001] and in the forestry and agriculture – for disinfecting nursery subsoils [Thuery 1992, Mavrogianopoulos et al. 2000, Clavell 2006, Słowiński 2010, 2013] or more efficient seed germination [Pietruszewski and Kania 2011, Cieśla et al. 2015]. Earlier investigations described the influence of microwaves onto the material and included a detailed discussion of changes in weight, temperature [Jakubowski 2008] and humidity. As far as live organisms are concerned, survival was tested depending on microwave power and impact time [Ikediala et al. 1999, Wang and Tang 2001]. Thermovision cameras were frequently used in developing surface heating characteristics [Mularz and Wróbel 2003, Błachnio and Bogdan 2004, Maciak 2004, 2009, Gajewska et al. 2010].

The authors of this article propose application of microwaves in the process of Scots pine cone husking, in particular in areas classified as resistant to opening [Aniszewska 2012a, b]. Subjecting the cones to radiation for several seconds during the first stage of cone husking contributes to quick loss of moisture from the cones, which results in cone husk movements and separation. Consequently, cones open and, during subsequent hours of traditional husking, seeds are obtained more quickly. An important factor is familiarity with the time of radiation and power emitted by the microwave antenna. According to the investigations conducted by Rukuni [1997], the time of microwave impact onto cones should not exceed 30 s.

Development of an overview of the process related to subjecting cones to microwave radiation involves characterisation of the dynamics of temperature changes on the outer surface of cones in time, which is presented in this article. The objective of conducted investigations was to analyse changes in temperature and heated area of cones exposed to microwave radiation. The investigations were conducted at five different levels of radiation power. The investigations did not involve analysing the quality of seeds from cones subjected to microwave radiation. Evaluation of seed vitality will be discussed in the following articles from this topic area.

MATERIAL AND METHODS

Cones of Scots pine (*Pinus sylvestris* L.) from Grotniki Forest Inspectorate (of the Regional Directorate for State Forests in Łódź) from seed cultivation tree stands, obtained in February 2013, were used in the investigations. Before the analysis, the cones were kept in a cold store, at the temperature of approximately 5°C. From the batch, 100 cones with a similar weight and outer dimensions were selected. Weight measurements were performed with the use of RADWAG WPS210S moisture balance with the accuracy of 0.001 g, whereas size parameters were measured by means of an electronic slide calliper with the accuracy of 0.1 mm.

After the measurements of weight and outer parameters, the identified cones were placed in a laboratory microwave oven and subjected to microwave radiation until the investigators observed bending of the first husks. Microwave radiation with the power of 800, 660, 440, 260 and 130 W was used during the investigations. While the cones were exposed to radiation, changes in the temperature of outer cone surface were measured. VIGOcam v50 thermovision camera was used in the investigations. The camera allowed measurement in the spectral range of 8–14 μm and obtaining of an image with the resolution of 384 × 288 pixels. The temperature measurement relative error was 2% of the measurement range. The investigations involved taking photographs, while pausing the radiation exposure process, of the outer surface of the cone – initially at the intervals of 5 s, and subsequently at the intervals of 10 and 20 s, depending on the applied wave power. Based on the photographs taken by the camera, analysis of the temperature and heating of the cone surface was performed. Temperature change results were analysed by means of THERM 2.13.3 software, whereas area of the heated surfaces was determined using MultiScan Base v. 18.03 software.

Once exposing the cones to microwave radiation ended, humidity was determined using the moisture balance method.

Registration of the ambient temperature and humidity was carried out during the investigations using Rotronic HygroPalm probe, with the accuracy of 0.1°C and 0.1%.

Statistica 10 statistical software was used to perform statistical analysis of the results.

RESULTS

Average weight of the analysed cones was 7.566 g (±0.295), length – 44.18 mm (±3.113), and thickness – 20.60 mm (±2.344). Absolute humidity of the cones was 29% (±2.3). Total time of microwave radiation was from 15 to 115 s, depending on the applied power. Ambient temperature in the room was on average 23.2°C, with the humidity of 50%.

Four photographs were taken with the thermovision camera for each of the cones subjected to radiation at the power of 800 W. The first photograph was taken before the test, with the following three taken 5, 10 and 15 s after its beginning. Radiation exposure was ended after 15 s, as slight opening of the first cone husks was observed. Based on an analysis of the developed thermograms it was concluded that, in each case, the temperature of the outer part of the cones was lower in the central part of the image than in the outer part.

With the radiation power of 800 W, the surface gradually heated up to 100°C. After 5 s, 9% of the observed surface reached 100°C, whereas after 15 s – already over 25%. Temperature differences read from the thermogram for subsequent seconds of microwave exposure are presented in Figure 1.

Reduction of the radiation power to 620 W prolonged the husk separation time to 30 s. Before the radiation process, the cone surface temperature was, as in the previous cases, approximately 7°C, but as soon as after 10 s the surface temperature changed on average by approximately 60°C. After another period of 20 s, the temperature grew to 120°C, with nearly 55% of the outer cone surface reaching this temperature (Fig. 2).

Once the microwave power of 440 W was applied (Fig. 3), the time required to initiate the husk opening process was also 30 s. Based on an analysis of the obtained thermograms, it can be concluded that the cone surface temperature did not rapidly grow to 100°C as it was the case with the radiation power of 620 W. With the investigated power of 440 W, a different distribution of temperatures was observed on the cone surface. In this case, the area on which the cone surface became heated to 86°C was growing gradually.

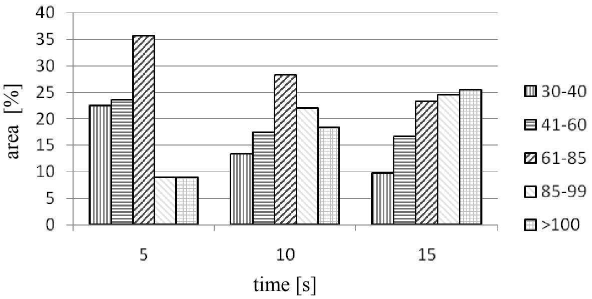

FIGURE 1. Change in the temperature and change in the heated up area of the cone surface during 15 s, in case of 800 W radiation

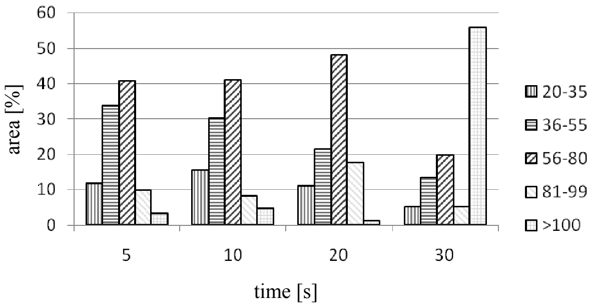

FIGURE 2. Change in the temperature and change in the heated up area of the cone surface during 30 s, in case of 620 W

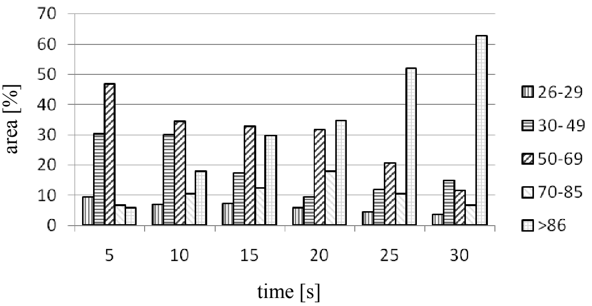

FIGURE 3. Change in the temperature and change in the heated up area of the cone surface during 30 s, in case of 440 W

When the radiation power of 260 W was applied, the time required to initiate the husk opening process was 55 s. Over the first 15 s of the process, the cone surface temperature did not change significantly (Fig. 4a). This results from the operation of the microwave oven magnetron, which switches on less frequently at lower power than in the case of higher power. In the central part of the outer cone surface, the temperature of approximately 12°C was observed, with the average temperature of 25°C observed at the edges. Durimg process, surface temperature started growing and reached over 100°C at 25 s. The reach of this temperature value covered 25% of the visible analysed surface of the cone; after 45 s, it covered over 50%. The area heated to the temperature of 55–74°C was gradually decreasing and the area with the temperature of 75–99°C was changing insignificantly (Fig. 4b).

temperature occurred, as it was the case with radiation of 260 W. The breakthrough moment in the process of heating with the power of 130 W was the period of 20–25 s, as temperature increase in the central part of the outer cone surface was observed (Fig. 5b).

In the case of exposing cones to microwave radiation with the lowest power (130 W) the phases of activation and pauses in the operation of the microwave

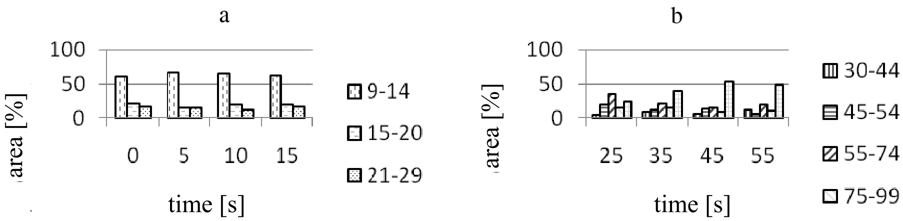

FIGURE 4. Change in the temperature and change in the heated up area of the cone surface in case of radiation power of 260 W: a – in the first 15 s, b – in subsequent 40 s

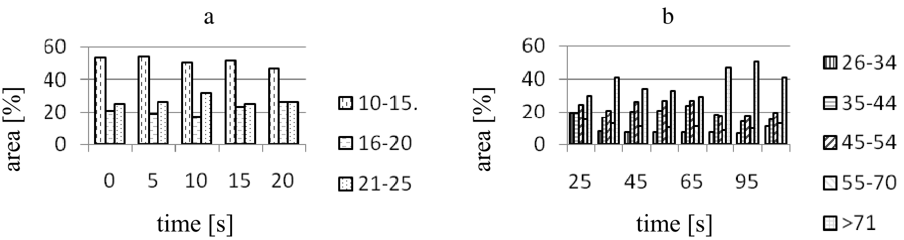

FIGURE 5. Change in the temperature and change in the heated up area of the cone surface, in case of radiation power of 130 W: a – in the first 10 s, b – in subsequent 95 s

Twelve photographs of the cones exposed to microwave radiation were taken with the thermovision camera, at the time of 5–115 s. Before the investigation in the laboratory microwave oven commenced, the temperature of the cone surface varied from 10 to 25°C and this value maintained for another 20 s of the process (Fig. 5a). During the next 95 s, significant growth in the cone surface oven magnetron may be observed, e.g. activation and emission of waves took place in at 35 and 75 s of microwave radiation, which resulted in rapid growth of temperature of the outer cone surface and increase in the surface with a temperature above 70°C. Despite the longest time of microwave radiation, the temperature above 100°C was not observed on the cone surface.

CONCLUSIONS

1. Growth in the power of microwave radiation results in faster heating of cone surface and shorter time elapsed before opening of the first husks on the cone. In the case of 800 W microwave radiation, the time of heating the outer cone surface to 100°C was 15 s, and the area with this temperature covered 25% of the cone surface. As far as 130 W radiation is concerned, opening of the first husks occurred after 115 s, and the outer surface temperature exceeded 70°C.
2. With the power levels of 260 and 130 W, two stages of microwave radiation impact were distinguished. The first one, in which the cone surface temperature does not change considerably and reaches the maximum value of 25°C, and the second one, characterised with temperature growth in the heated surface to over 70°C. The dynamics of temperature changes is caused by the operation of the microwave over magnetron.
3. Presented results allow the assumption that, in order to initiate opening of cone husks, it is the most beneficial to apply radiation with the power of 440 W. Application of this power enables initiation of the husk opening process within 30 s, without causing excessive heating of the cone. At lower microwave powers, the cone exposure time was significantly longer than 30 s, which, according to Rukuni [1997], is detrimental to their subsequent sprouting.

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Streszczenie: *Dynamika zmian temperatury powierzchni zewnętrznej szyszek sosny zwyczajnej (*Pinus sylvestris *L.) poddanych promieniowaniu mikrofalowemu.* W artykule przedstawiono wyniki badań, których celem była próba opisu dynamiki zmian temperatury powierzchni zewnętrznej szyszki poddanej działaniu promieniowania mikrofalowego. Do analizy procesu autorzy wykorzystali termogramy wykonane kamerą termowizyjną. W badaniach wykorzystano zamknięte szyszki z gospodarczych drzewostanów nasiennych z Nadleśnictwa Grotniki. Szyszki poddano działaniu mikrofal o mocy 800, 620, 440, 260 i 130 W do czasu zaobserwowania otwarcia pierwszych łusek na ich powierzchni. Autorzy stwierdzili, że najodpowiedniejszą wartością mocy dla etapu wstępnego obniżenia zawartość wody w szyszkach jest promieniowanie 440 W. Przy tej mocy czas oddziaływania na szyszki promieniowania mikrofalowego wynosi 30 s.

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