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On the Possibility of Marking Eggs with a CO_2 Laser

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***Abstract* - A number of policies and standards regarding food safety issues and quality management have been established for the food industry. One of these requirements is related to the marking of food products describing the expiration date, content and quality. The report examines the possibility of using laser technology to mark chicken eggs. The contrast of the laser marking is the main criterion for determining its quality. The study examines the functional dependences of the contrast on the main technological parameters of the marking process: laser output power (7 – 20.3 W) and processing speed (50 - 300 mm/s). As a result of the research, optimal parameters for marking with a technological laser system CO_2 have been determined.**

Keywords - laser marking, marking of eggs, CO2 laser, laser engraving

I. INTRODUCTION

Today, in most countries of the world, food safety is very important. A number of norms and standards for food safety and quality have been developed for the food industry [1]. One of these requirements is related to the marking of food products describing the expiration date, content, quality, etc. Tracking is one of the key tools for achieving quality and safety standards. Tracking allows you to determine the current location of the product, its origin and expiration date, and also provides information about processing, retailing and the final purpose of goods [2]. To ensure high quality in the trading network, automated systems are often used. Technologies for automated identification of goods and data collection are based on barcodes, QR codes, optical recognition of encoded information, etc.

One of the most popular foods is chicken eggs. According to the International Independent Institute for Agrarian Policy (МНИАП), since 2000, the total production of chicken eggs has increased by 1.4 times, and by 2035 the consumption of eggs in the world will increase by 50% [3]. Chicken eggs are usually marked with an alphanumeric code. Fresh eggs of class "A" - intended for human nutrition, are marked with a code consisting of numbers and letters [4] (see figure 1).

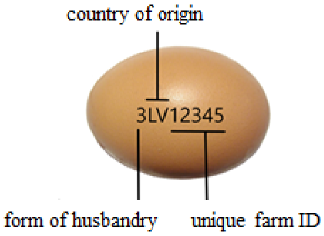

Figure 1. Marking a chicken egg with an alphanumeric code.

Traditionally, eggs are marked with an ink seal. This method of marking has such disadvantages as the need for chemical dyes, environmental pollution, the need for time for the ink to dry.Laser technology has developed at a very fast pace in recent decades. One of the main applications of laser technology is laser marking. Laser marking is also used in the food industry. The laser creates markings on the eggshell without the need for additional materials such as ink, while ensuring outstanding marking quality and consistency. Unlike ink markings, laser markings are not erased or smudged. The advantages of laser marking also include high speed, repeatability, efficiency and low operating costs. The method is non-contact, does not require a special working environment and can be easily automated and integrated into production lines. [5,6,7,14,15]

The aim of the present study is to analyse the capabilities of one industrial CO_2 laser system for marking eggs, to determine the optimal operating intervals for power and processing speed to achieve optimal marking contrast [8].

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II. PROCESS RESEARCH EQUIPMENT

In the experimental studies we performed for marking the eggs we used a CO_2 laser technological system with a wavelength λ = 10.6 µm. Synchronous control of the on / off laser generation and the movement of the laser beam focusing system along a given contour along the X, Y axes, as well as the change in the laser radiation parameters, is carried out using a special computer program. A schematic diagram of an experimental setup for marking chicken eggs is shown in figure 2a. In the experiments we used the raster laser marking method (figure 2b).

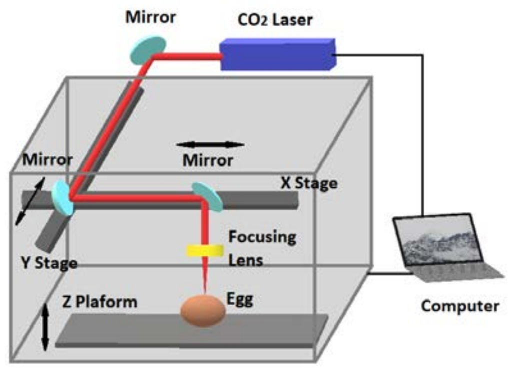

Figure 2a. Schematic diagram of an experimental setup for marking chicken eggs using a CO_2 laser.

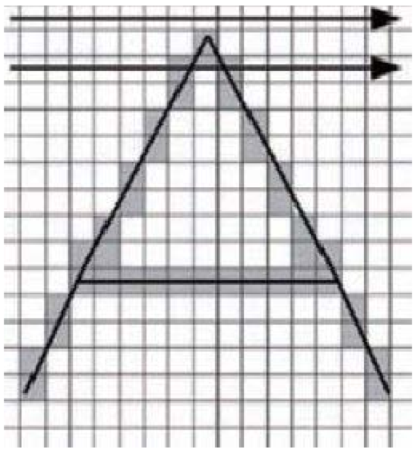

Figure 2b. Raster method of laser marking.

The main technical parameters of the CO_2 laser system SUNTOP ST-CC9060, with which the experiments were performed, are listed in table 1.

TABLE 1. TECHNICAL PARAMETERS OF CO2 LASER SYSTEM SUNTOP ST-CC9060

Laser type	CO_2 laser
Operation mode	CW
Laser wavelength	10.6 µm
Max. laser power	100 W
Process size	900 x 600 mm
Scanning speed	0 – 1000 mm/s
Positioning accuracy	<0.02 mm
Focal length	63.5 mm

The Ocean Optics STS VIS microspectrometer was used to determine the contrast in the measurements, measuring the reflectivity *R* [%] of the treatment area and comparing it with that of the surrounding surface. A schematic diagram of measuring the reflectance *R* [%] of the egg shell surface using a microspectrometer is shown in figure 3a. The reflected light spectrum from the unmarked egg shell surface (brown) and from the CO_2 laser marked egg shell surface is shown in Figure 3b.

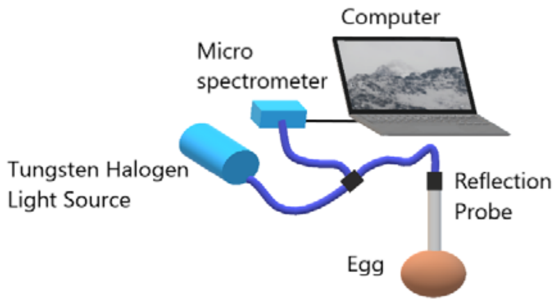

Figure 3a. Schematic diagram of measuring the reflectance *R* [%] of the surface of the shell of chicken eggs.

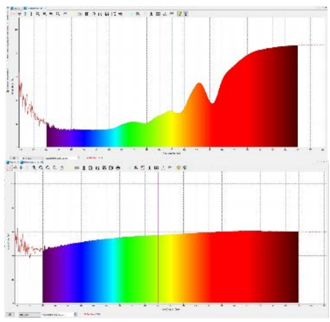

Figure 3b. The reflected light spectrum from the unmarked egg shell surface (above) and from the CO_2 laser marked egg shell surface (below).

III. SPECIFICS, PROPERTIES AND STRUCTURE OF THE MATERIAL SUBJECTED TO LASER TREATMENT

The shell of a chicken egg is a hard, porous shell. From above, the shell is covered with a thin over-scaled shell - cuticle, and from below it is firmly connected with a two-layer under-scaled shell. The cuticle is not strong and is easily destroyed by mechanical action (washing with brushes, etc.), but it protects a fresh egg from the influence of the external environment. The basis of the shell is a network of collagen-like protein fibers and an intermediate inorganic substance, which contains mainly carbonate and phosphate salts of calcium and magnesium, which provides a certain strength and resistance to mechanical stress. [9]

For a chicken egg, the shell has a thickness of 0.34 – 0.40 mm. The thickness of the eggshell depends on the mineral content of the feed. In the structure of the shell, two layers are distinguished. The outer layer is spongy and occupies 2/3 of the entire thickness. The inner layer is prismatic. The shell of a chicken egg has about 7000 through pores with a diameter of 4 to 40 microns. As a result, the shell is permeable to gases, water and water vapor. The permeability of the shell to air is the same in both directions (from the inside and from the outside). Water enters from the outside into the middle as slowly as from the inside into the external environment. The permeability of the shell for carbon dioxide is better than for air, and vice versa for oxygen. The density of the shell is 2.14 – 2.17g/cm^3. [9,10]

Figure 4 shows the microstructure of an eggshell. The shell of a medium-weight chicken egg consists of 1.6% (0.1 g) of water, 98.4% (6 g) of dry substances, including organic - protein 3.3% (0.2g), lipids 0.03 (traces) and 95.1% (5.8 g) of inorganic substances. The shell mineral is 99% calcium carbonate. In eggs of birds with a hard shell, it exists in the most thermodynamically stable form - calcite. Inorganic phosphate, magnesium, zinc, copper, manganese, selenium and other elements that are present in small quantities can have a certain effect on the quality of the shell. [9]

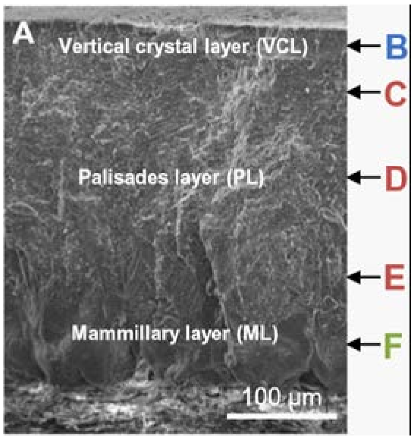

Figure 4. Microstructure of poultry eggshell, SEM (Scanning Electron Microscope) image. [11]

For chicken eggshell typical is structure with nano granules of various sizes (from 50 to 100 nanometres). Five layers can be distinguished with different average sizes of nanostructures, and this size increases from the outer layers of the shell to the inner ones. Figure 4: B - outer vertical crystalline layer VCL; C, D, E - middle columnar (palisade) layer PL, F - inner layer of hemispherical aggregates (mammillary) ML. [9,12]

IV. FACTORS AFFECTING THE PROCESS OF MARKING, AND METHODOLOGY FOR THE EXPERIMENT

In general, factors that affect the laser marking process can be divided into 3 main groups (figure 5a). Depending on the choice of the technological system and the mode of operation (pulse or CW mode), as well as the method of marking, the process affecting factors also change. In our study, due to the fact that the CO2 laser technological system operates in CW mode and only two methods are used (ablation and engraving), there are six factors that affect the contrast of the marking (figure 5b). These are: laser power density qs [W/cm2] (respectively the energy density Es [J/cm2]); marking speed v [mm/s]; distance between raster strokes Δx [mm] (raster step); focus offset Δf; number of repetitions; color of the treated surface. Laser power density represents laser source parameters. Marking speed, raster step, focus offset, and number of repetitions represent the parameters of the technological system and the method used. In terms of material properties, this is the color of the treated surface. In our specific case, the color of the examined chicken eggs is brown.

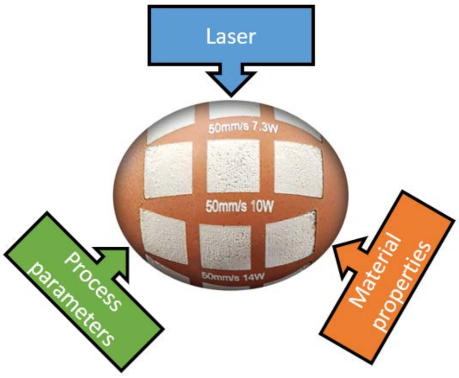

Figure 5a. Three main groups of factors that affect the laser marking process.

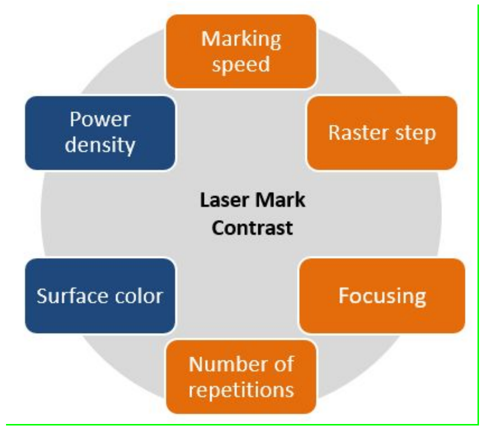

Figure 5b. Six factors that affect the contrast of the marking

The methodology of the experiment in the present study is related to the analysis of the contrast *k* as a function of the processing speed *v* and the power *P* of the laser radiation. Two series of experiments were carried out in which one of the two main parameters, processing power *P* and the speed *v* of the beam on the treated surface, was kept constant. The rastering method of marking is used to fill in a 10x10 mm square with a constant pitch between the raster lines Δx = 0.1 mm. This size made it possible to subsequently measure the reflectance *R* of the treated area using a microspectrometer (figure 5a) and calculate the contrast *k*.

In the first series of experiments *k* = *k (P)*, the contrast *k* is studied in the range of power *P* change from 7.3 W to 20.3 W at six constant marking speeds *v*, respectively (50; 100; 150; 200; 250; 300 mm/s).

In the second series of experiments *k* = *k (v)*, the contrast *k* is investigated in the range of variation of the velocity *v* from 50 mm/s to 300 mm/s sequentially for six constant laser radiation powers *P*, respectively (7.3; 10; 12; 14; 17; 20.3 W). A total of 72 experiments were carried out and related measurements of the reflectivity *R*. The choice of research ranges for power *P* and speed *v* was made on the basis of our previous studies [13] related to the study of the functions *b* = *b (P)* and *h* = *h (v)*, where *b* and *h* are the width and depth of the marking lines on the treated surface. The aim was to achieve the depth *h* of the treated area less than 1/5 of the thickness of the chicken egg shell (0.34 ÷ 0.40 mm) and at the same time to achieve the maximum contrast *k* of the marking area. It should be borne in mind that the depth of the stained area per eggshell is only 150µm.

V. RESULTS OF EXPERIMENTAL STUDIES

The results of experimental studies of the effect of laser radiation power on the contrast of the marking zones are shown in figure 6a. We can see contrast versus power graphs for three different processing speeds: 50 mm/s; 150 mm/s and 300 mm/s. It is clearly seen from them that in the range from 7.3 W to 14 W, the contrast *k* increases nonlinearly for all three marking speeds, and in the range from 14 to 20.3 W, the dependence is almost linear. For the entire studied interval of power *P*, the contrast *k* in absolute value increases by about 14-16%. In order to better find out which of the two working intervals is more advantageous for operation from a technological point of view, ratio *Δk/ΔP* was calculated in the power range from 7.3 W to 14 W and from 14 W to 20.3 W. The results of these calculations are shown in Table 2.

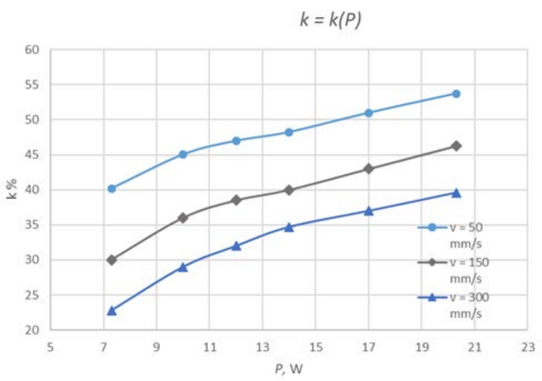

Figure 6a. Contrast *k* as a function of power *P*.

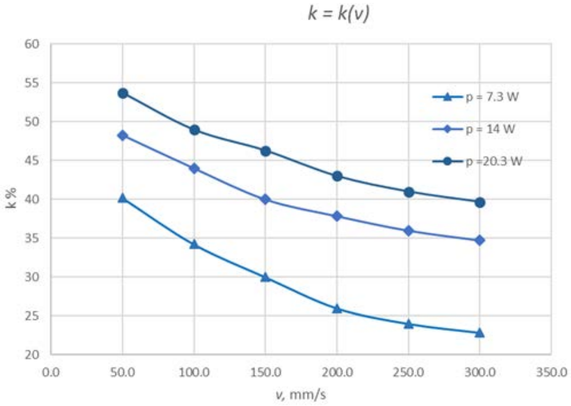

Figure 6b. Contrast *k* as a function of speed *v*.

The analysis of the results of experimental studies of the effect of the processing speed *v* on the contrast *k* is summarized and presented in the graphs (figure 6b). The graphs shows three dependences of the contrast *k* on the velocity *v* for three different laser radiation powers 7.3 W; 14 W and 20.3 W. For the investigated range of velocity *v* from 50 mm/s to 300 mm/s, a nonlinear decrease in contrast *k* is observed for all three laser powers. Comparing the three power graphs shows that the graph with *P* = 7.3 W has a greater slope than with 14 W and 20.3 W.

In order to better find out where the most successful working intervals are from the technological point of view, the rate of contrast change *Δk/Δv* was calculated in the speed range *v* from 50 mm/s to 300 mm/s. For better visualization of the analysis, the interval of velocity *v* is divided into two sections: 50 ÷ 200 mm/s and 200 ÷ 300 mm/s. The results of these calculations *Δk/Δv* are shown in Table 2.

TABLE 2. THE RATE OF CONTRAST CHANGE ΔK / ΔP, [%/W] IN THE POWER RANGE AND THE RATE OF CONTRAST CHANGE ΔK/Δ V [%/MM·S-1] IN THE SPEED RANGE.

Speed v, (mm/s)	Power P, 7.3 ÷14 W	Power P, 14 ÷20.3 W	Power P, (W)	Speed v, 50÷200 mm/s	Speed v, 200÷300 mm/s
50	1.8	0.70	7.3	0.093	0.03
150	1.5	0.95	14.0	0.07	0.035
200	1.2	0.75	20.3	0.073	0.04

Analysis of the graphs and tables shows that the lowest values of the contrast change rate are in the range for powers *P* - 14 ÷ 20.3 W and for processing speeds *v* - 200 ÷ 300 mm/s.

Finally, the following recommendations can be made from this analysis: In this research, as the recommended operating interval for optimal contrast (more than 35%) for the studied power ranges *P* = 7.3 ÷ 20.3 W and speed *v* = 50 ÷ 300 mm/s.

There may be recommendations as follows:

P = 14 ÷ 20.3 W. in the range for processing speed *v* = 200 ÷ 300 mm / s.

In this analysis, we were guided by two factors that are related to the optimization process:

- on the one hand - reading the markings, both visually and with the help of automatic recognition systems.
- on the other hand - to achieve a high processing speed *v* (200 ÷ 300 mm/s) with an optimal operating power *P* (14 ÷ 20.3 W) for a specific technological CO_2 laser system.

Another feature that we registered during the research is that in the area of marking there is no melting of the main material from which the eggshell is made. The interaction of the marking process is related to the sublimation method of processing, i.e. we have direct destruction and dusting of the base material.

VI. CONCLUSION

The ability to spot the right area, label and evaluate a product right on production lines is critical for laser marking of food and especially for chicken eggs. This study was divided into three phases.

First, the study was aimed at clarifying the geometry of the marking zone and its functional dependencies on technological processing parameters. The results of this study were published at the scientific conference "Radiation Safety in the Modern World" of the National Military University "Vasil Levski" in year 2019 in Bulgaria.

At the second phase - there was a research of the influence of the power of technological parameters P and the processing speed v on the achievement of the optimal contrast k in the range from 35% to 55%, which was the subject of this study.

The third phase - future of our research is related to the development of algorithms for determining the optimal position of the marking on the surface of chicken eggs. This is due to the fact that the eggs have a specific oval shape, which, in turn, affects the focusing and defocusing of the workpiece during laser processing.

The generalization of these three studies will ultimately lead to optimization of laser marking parameters and providing contrast, and stable marking that is correctly positioned on the working surface of the eggs.

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