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Modification of the rheological properties of honey in the honeycombs by the high frequency heating prior to honey extraction

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Abstract. This paper addresses the issue of the extraction of highly viscous honey from the honeycombs. High viscosity can be caused by many factors. In the operational practice it is mainly about the difficult conditions (cold weather), post seasonal honey extraction or honey with naturally high viscosity (honeydew honeys). The objective was to design and validate a technology that will enable to reduce the viscosity of honey in the honeycombs by the high frequency heating and increase the effectiveness of honey extraction. The experimental part is based on the high frequency heating of honey, so called dielectric heating. In this process the heating of honey occurs evenly throughout the full volume of the honeycomb. To verify the proposed procedure, several groups of samples of the capped honeycombs were selected that contained honey of different botanical origin and rheological properties. For heating of the honeycombs, a high frequency chamber was prepared in the laboratory conditions. Honeycombs were placed into the chamber and heated to the desired temperature (from 15 °C to 45 °C). During extraction, the time dependence of honey extraction on the temperature of the pre-heated honeycombs was monitored. It was proved that the high frequency heating is suitable for the pre-processing of the honeycombs; heating is quick and reduces the viscosity. As a consequence of different permittivity of honey and beeswax, the strength of the comb is not changed when the electromagnetic field conditions are set properly, the honeycomb remains compact. Measurements demonstrated the time reduction of honey extraction based on the temperature.

Key words: honey, honey extraction, high frequency heating.

INTRODUCTION

The present paper experimentally deals with the issue of the extraction of the viscous honey from the capped honeycombs. This technological operation is challenging if the honey does not have an ideal liquidity. It is when honey is extracted during adverse weather conditions or if a highly viscous honey that bees make in some seasons is extracted. The objective of this paper was to design and validate the possibility of changing the rheological properties of honey in the production conditions by heating of the whole honeycombs in order to increase the liquidity of honey. The higher temperature of honey enables the better operational processability of the honeycombs. An increase of the productivity and yield of honey from the honeycombs can be expected.

From the technological point of view, honey is a liquid which is difficult to process. Processability is influenced by its chemical composition and physical properties (Fischer & Windhab, 2011). Technologically important are the rheological properties of honey. They affect the honey processing technology, i.e. honey extraction from the honeycombs, pumping, churning, straining, filtration, mixing and filling honey into consumer packaging (Escriche et al., 2009).Rheological properties are mostly influenced by the degree of crystallization and viscosity of honey. The degree of crystallization is dependent on several factors of which the most important are the ratio of glucose and fructose and the presence of pollen grains (Escuredo et al., 2014). Honey viscosity is dependent on water content in honey, chemical composition and temperature (Gleiter et al., 2006). Water content and chemical composition of honey is determined by its botanical origin and cannot be changed in the operation conditions for honey processing. It would cause irreversible changes in the quality of honey. Given the fact that some properties (e.g. water content) are at the same time the indicators of product quality, their technological change would be in breach of the legislation (Turhan et al., 2008). On the other hand, the influence of temperature change on the viscosity of honey is technologically feasible in practice and is regularly used. The heating of honey or the heating of the honeycombs shall be performed in a friendly manner. The overheating or repeated heating may cause changes in chemical composition of honey and the quality deterioration. The quality indicator of the technologically deteriorated honey is the content of hydroxymethylfurfural (HMF). The unheated honeys contain about 10 mg per kg of HMF. The maximum allowed amount is 40 mg per kg for single–flower honeys (mixed honeys 80 mg per kg). The higher amount indicates the old age of honey or the technologically improper heating of honey.

The temperature dependence of viscosity is a logarithmic function – there is a big change in viscosity at low temperature change (Gomez–Diaz et al., 2009). Honey viscosity (regardless the botanical origin) decreases with increasing temperature and such decrease reaches its maximum at a temperature around 40 °C. In the temperature range of 10 °C to 40 °C viscosity of honey gradually decreases from 100 Pa s to 2 Pa s (Yanniotis et al., 2006). The above values show that the temperature at which the viscosity of honey is low is technologically advantageous for honey extraction from the honeycombs, mixing and other processing procedures. Technologically, there are several ways to extract honey from the honeycombs. In practice, gravitational force, pressure force or centrifugal force are used for honey extraction. In all cases, the effectiveness and efficiency of the process depend on the rheological properties of honey. Well-established practice is to extract honey by centrifugal force on honey extractors of various constructions. Extraction efficiency is dependent on centrifugal force and the properties of honey. Increasing efficiency by increasing the centrifugal force, i.e. the speed increase and the radius of rotation of the drum of the honey extractor, is limited by the strength of the beeswax comb (the risk of damage and contamination of honey by beeswax). Therefore in the production conditions for honey extraction a change in honey's rheological properties is sometimes used prior to the uncapping of the honeycombs. It's about the increase of temperature by the conventional heating and thus reducing viscosity, which affects the efficiency and speed of honey extraction (Oroian et al., 2013). This process is time consuming and laborious.

The proposed technology solves the problem of reduction the viscosity of honey by heating the capped honeycombs by high frequency dielectric heating. Dielectric heating and microwave heating are based on the direct transmission of the electromagnetic energy to the heated material. Compared to the conventional methods of heating the processing time is short and the heat is generated in the full volume of the heating material. For honey, as well as for the other organic materials, the heating characteristics are influenced by frequency, water content and dielectric properties of the heated material (Sosa–Morales et al., 2010). Dielectric properties of honey, i.e. relative permittivity and dielectric loss factor are a function of frequency, water content in honey (Puranik et al., 1991) and less important also temperature (Guo et al., 2011). For natural honeys, the relative permittivity decreases with increasing frequency. For the frequency range of 10 MHz to 1000 MHz the honey relative permittivity has values from 40 to 13 (Puranik et al., 1991).

This study is based on the assumption that the high frequency heats the honeycomb evenly throughout all of its volume; is faster compared to the conventional heating and friendly for the honey quality. The objective was to propose and validate a technology that will enable to reduce in adverse climatic conditions the viscosity of honey in the honeycombs by high frequency heating. This will create conditions for reduction of the overall time of the honey extraction from the honeycombs and increase the efficiency of honey extraction.

MATERIALS AND METHODS

The following procedure was used to verify the possibility of changing the rheological properties of honey in the honeycombs by warming up by high frequency heating.

Samples of the capped honeycombs from two different seasonal periods were selected. Thus, there were two groups of honey samples of different botanical origin and different rheological properties available. Honeycombs were heated to the desired temperature from 15 °C to 45 °C, always by 5 °C. The temperature of honey was increased by high frequency dielectric heating. Once the desired temperature of the honeycombs was reached, the honeycombs were uncapped, inserted into the honey extractor and were extracted to dry, i.e. to reach the complete extraction of honey. The time required to extract all honey from the honeycombs was measured.

Honeycombs

The properties of the honeycombs heated by the high frequency source were measured in two groups of the honeycomb samples. The honeycombs from the first sample came from a spring period and contained nectar honey. The honeycombs from the second sample came from a summer period and contained honeydew honey. The first and the second sample differed by the botanical origin of honey and further by its physical and chemical properties. Thus the requirement that each sample contained honey of different rheological properties was met. For both samples, the refractometric method for determining the water content was used (water content significantly influences the dielectric properties of honey). In both cases, it was confirmed that they contained mature honey. Nectar honey contained 18.2% of water, honeydew honey 18.9% of water:

1. Sample: nectar honeyfrom May 2016.
2. Sample: honeydew honeyfrom July 2016.

Honeycombs heating

The temperature of the honeycombs was increased from the original temperature of 15 °C by the high frequency dielectric heating. A device established in the laboratory conditions was used for the heating. The device is shown in Fig. 1. The device consists of a heating chamber (1) and a high frequency generator (4). The heating chamber (1) is designed as two plates (2) of dimensions of 0.3 x 0.4 m. The plates are mutually fixed at a distance d at the value of 0.1 m. For heating, the honeycomb (3) was inserted into the heating chamber (1) and the high frequency generator (4) was switched on. The heating time was calculated based on the desired temperature of heating.

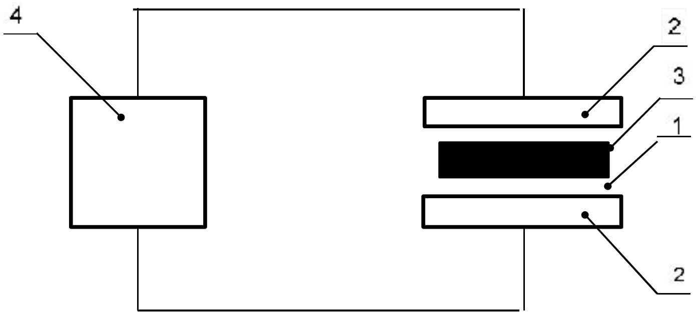

Figure 1. Connection scheme of the device for the high frequency heating of the honeycombs: 1 – heating chamber; 2 – heating surface plates; 3 – honeycombs, 4 – high frequency generator.

Operating parameters of the high frequency dielectric device (voltage, frequency) and operating conditions of heating (heating time) were calculated from the general physical equations. For the calculation, the relation between the heat output density on the side of the heated material, i.e. honeycombs (1) and the heat output density of the high frequency source, i.e. the heating device (2) was utilized.

$$Q_1 = \frac{\rho \cdot c_p \cdot \Delta T}{t} \tag{1}$$

where: ρ – density of honey; c_p – specific heat capacity of honey; ΔT – difference in temperature; t – heating time.

$$Q_2 = 2 \cdot \pi \cdot f \cdot \varepsilon_o \cdot \varepsilon_r \cdot tg\delta \cdot E_{ef}^2 \tag{2}$$

where: f – frequency; ε_o – vacuum permittivity; ε_r – relative permittivity of honey; E_{ef} – effective electric field intensity ($E_{ef} = U_{ef} \cdot d^{-1}$); d – distance between the plates; U_{ef} – voltage; $tg\delta$ – loss factor.

For calculation, honey was specified by density 1,400 kg m^{-3}, specific heat capacity 3,000 J kg^{-1} K^{-1}, loss factor 0.1 and relative permittivity of honey 17.6 at 500 MHz (Puranik et al., 1991) and original temperature 15 °C. The high frequency generator with an operating frequency 500 MHz and voltage 2,000 V was used for the heating. The frequency 500 MHz was chosen due to the possibility of using low operating voltage gradients.

Honey extraction

Honey extraction from the honeycombs was performed on a commercially produced honey extractor. Honey extractor EWG 4 Comfort of Heinrich Holtermann brand is a four-frame reversible tangential honey extractor with automatic control. During extraction, the control mechanism was adjusted so that the process corresponded to normal operational practice of honey extraction. The tangential reversible honey extractor worked in two phases. The first phase of honey extraction was conducted using low speed rotation (30 min^{-1}) to one and the other side – for 1 minute each. The second phase of honey extraction was conducted using high speed rotation (60 min^{-1}) for one and the other side – for the time necessary to extract all honey from the honeycomb.

RESULTS AND DISCUSSION

The usability of the high frequency heating of the honeycombs for the purpose of changing the rheological properties of honey was in the operating conditions measured as the time dependence of honey extraction on the temperature of the pre–heated honeycombs.

Heating of the honeycombs by the high frequency heating does not allow the usage of a suitable thermostatic control automation system for the precise adjustment of the heating temperature. The usage of the control automation system would require an installation of a thermometer sensor into honey in the heated honeycomb. The thermometer sensor has different physicochemical properties than honey and thus has a different permittivity value than the heated honey. It is heated differently from honey in the high frequency field. In order to reach the desired temperature of honey, it was necessary to measure the heating time for each selected temperature of the pre-heated honeycombs. The measurement of the heating time was carried out according to the equations (1) and (2). In order to obtain an accurate temperature of honey, control measurements by a digital needle probe thermometer were carried out. In Table 1, there are listed measured heating times of the honeycombs and temperatures measured with the thermometer after the high frequency heating. From Table 1 follows that the heating times of honey in the honeycombs are under specified conditions in the units of minutes. This suggests that the high frequency heating has at set conditions for heating of honey high efficiency. The measured heating times (in order to reach the desired temperature) and subsequently measured temperature values by control measurements show minimal deviation between desired (i.e. set) and achieved (i.e. measured) temperature of honey. This deviation moves to 2 °C. This difference is insignificant in the operating conditions.

Table 1. Measured heating times of the honeycombs for the desired temperatures and actual temperatures measured with a thermometer after the high frequency heating

		Sample number 1	Sample number 2
Temperature set [°C]	Heating time [min]	Temperature measured [°C]	Temperature measured [°C]
15	0	15	15
20	1.5	21	20.1
25	2.9	23.5	23.3
30	4.5	28.4	30.6
35	6	33.4	36.1
40	7.5	39.2	40.4
45	8.9	44	45.8

In addition, the temperature measurements at various locations of the honeycombs proved that the honeycomb is heated over the whole surface evenly. The evenness of heating the honey to a depth of the honeycombs has not been measured. The evenness of heating is given by the chosen method of heating, i.e. high frequency heating, in which the heat is generated evenly throughout the whole volume of the heated material. The evenness of heating depends on the penetration depth which is dependent on the relative permittivity, loss factor of a material and frequency. For pure honeys, the penetration depth decreased with increasing frequency linearly in log-log plot. The values of penetration depth of natural honeys in the range of 10 MHz to 1 GHz move between the range from 0.1 meter to 1 meter (Guo et al., 2011). For the honeycombs heating at a frequency of 500 MHz, which was used in the measurement, the penetration depth is sufficient.

The needle probe thermometer also measured the temperature of the beeswax, which forms the honeycombs and its caps. In this paper the concrete measured values of the temperature of the beeswax are not mentioned because they were monitored for guidance only as a secondary supplementary factor and were not accurately recorded. The honeycombs' beeswax had after the high frequency heating the temperature which was up to 8 °C lower than the reached temperature of the honey (for honeys at temperatures above 30 °C). The reason is the low permittivity of the beeswax. Beeswax has relative permittivity 3 (Prava & Ahmed, 2013). The difference in temperature reached between honey and beeswax for high frequency heating is beneficial for practice. The beeswax when heated does not change its rheological properties. It remained firm and thus the entire combs maintain their strength and dimensional stability. This is advantageous for the honey extraction from the honeycombs. The honeycombs when extracted were less damaged and the amount of beeswax in the extracted honey was lower, i.e. the extracted honey had higher purity (honey purity was assessed only subjectively).

Measured extraction times of honey at temperatures set in the interval between 15 °C to 45 °C are shown in Table 2. The temperatures indicated in Table 2. are temperatures measured by control measurements by the thermometer, i.e. the exact honey temperature reached.

Table 2. The values of honeycombs' temperature and time required to complete the extraction

Sample number 1 time [min]	Sample number 2 time [min]	Sample number 1 temperature [°C]	Sample number 2 temperature [°C]
10	12	15	15
8	10	21	20.1
6	8	23.5	23.3
6	6	28.7	30.6
4	6	33.4	36.1
2	4	39.2	40.4
2	2	44	45.8

Dependence of the measured factors shows Fig. 2. In Fig. 2 the values from Table 2 are laid out in a graph and they are interlaid with a trend connecting line. The curves thus obtained show progress of the time dependence of honey extraction on the temperature of the pre–heated honeycombs. The time figure represents the minimum time of the extraction required to extract all the honey from the honeycombs.

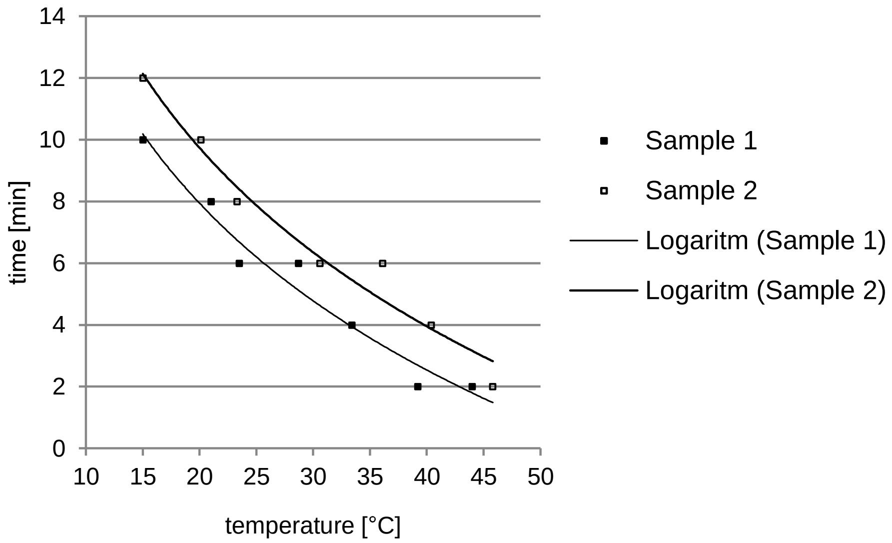

Figure 2. Dependence of honey extraction time on the temperature of the honeycombs.

The illustrated dependencies imply that the time necessary to extract honey from the honeycombs is dependent on temperature. The relationship between the time and the temperature of honey best describes logarithmic trendline of the measured values. It indicates that at a decreasing temperature i.e. temperature below 20 °C, there is a significant increase in the time required to extract the honeycomb. On the contrary, at temperatures above 35 °C, the shortening of the extraction time during increasing temperature is operationally insignificant. Technological optimum temperature for honey extraction from the honeycombs is within the temperature range of 25 °C to 35 °C. In the climatic conditions in the Central Europe, the possibility of honey extraction at these optimal temperatures is rather exceptional. This confirms the assumption of operational necessity of the honeycombs heating to the temperatures above 25 °C even during the honey extraction in the spring and summer.

The measurement proved that the course of dependency of the time required to extract honey on the temperature is similar in both samples. This means that the botanical origin of honeys and following differences in the chemical compositions of honeys have only minimal effect on the rheological properties of honeys. These results are consistent with previous research (Jehlička & Sander, 2016). Significant influence on the rheological properties has the reached temperature of honey. Botanical origin and related chemical composition impacts in each sample only mutual shift of the plotted dependencies. As follows from Fig. 2, this is a prolongation or shortening of the total extraction time of honey from the honeycomb for about 1 minute. The plotted curves indicates that the rheological properties depend mainly on the temperature and that the botanic origin of honey (chemical composition of honey) is operationally less significant factor.

From a technological point of view, the optimal temperature for the extraction of the honeycombs can be considered a temperature at which the honeycombs are extracted in a short period of time. Then, the plotted dependencies on Fig. 2 imply that extraction time depends mainly on honey temperature. It reaches its minimum at all observed samples after reaching a temperature about 30 °C. The optimal temperature for the honeycombs extraction can be considered a temperature between 25 °C to 35 °C, which corresponds to the extraction time of 4 to 6 minutes.

CONCLUSIONS

The measured values proved that the rheological properties of honey can be changed by high frequency heating. Highly productive heating can be achieved and once the honey of the optimal rheological properties is extracted then also high efficiency, i.e. to minimize the residual (unextracted) honey in the honeycombs.

The measurement was carried out only for the operating frequency set at 500 MHz, which corresponds to the relative permittivity of honey 17.6. It can be assumed that by changing the frequency used, the change in the intensity of heating will occur and thus the change of the heating time of the honeycombs. The risk of overheating of honey will increase with increasing frequency and consequently the possibility of the deterioration of honey quality. This dependence would be worthy to prove by another measurement in the future.

Furthermore, the measurement also proved a different effect of high frequency heating on honey and beeswax. Unlike the conventional method of heating, the high frequency processing causes different temperature increase in honey and beeswax. The beeswax did not change its rheological properties, remained solid and dimensionally stable. Extracted honey was not polluted by the residues of the loose honeycomb beeswax.

The monitoring of the dependency of the extraction time on temperature of the honeycomb proved that the rheological properties of honey are significantly affected by the degree of the temperature reached. The botanical origin of honey influences its rheological properties only minimally and its impact in the production conditions is negligible. Optimal rheological properties for the processing of the honey in the honeycombs are at temperature between 25 °C to 35 °C, at which point the time required to extract the honey from the honeycombs reaches its minimum.

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