Real-time monitoring of meat drying process using microwave spectroscopy

Magomed Muradov*, Jeff D. Cullen, Badr Abdullah, Muhammad Ateeq, Alex Mason, Andy Shaw and Ahmed I. Al-Shamma'a

School of Built Environment
Liverpool John Moores University
Liverpool, UK
*M.Muradov@2009.ljmu.ac.uk

Abstract — **The objective of this investigation is to monitor the meat drying process and try to analyse the changes of the electromagnetic (EM) signature from a patch antenna during the process. The antenna has been modelled using High Frequency Structure Simulation Software (HFSS) and then constructed. The experimental work carried out by placing a meat sample on a scale inside the fridge and recording reflection coefficient (S_{11}) and weight measurements 24 times (every hour) a day during one month at the frequency range of 1GHz-6GHz. Then, the change in EM signature and weight loss is correlated and analysed. The results demonstrate a relationship between the reflection coefficient and weight loss of the meat sample. The weight of the sample drops down dramatically first week and then keeps steadily decreasing. Likewise, an amplitude shift is greater at the beginning of the drying process and then the shift stabilises.**

Keywords-component; dry-curing; microwave sensor; non-invasive sensor; real-time meat analysis

I. INTRODUCTION

Electromagnetic sensors, and mainly microwave sensors, are widely used in a variety of industrial sectors. Examples include, civil engineering materials analysis [1] , timber imaging [2], chemical processing [3-5] and medicine [6-7] . However, there has yet to be a significant impact of microwave sensors in the food industry, with the majority of microwave-based technology there being centred on cooking and sterilisation. One possible reason for this is that products in the food industry are quite complex and delicate, thus the control of the process optimisation needs to be on a high level. In food matrices the relevant variables are structure, composition (particularly water content), water state and water distribution in the product and particularly water content profiles. Some tools to quantify these parameters do exists, but these methods often have disadvantages, such as being requiring contact with food products (or worse, they are invasive), which is not practical for the food industry since it possible for spoiling to occur. The solution to this problem is non-invasive EM sensors [8].

Products of certified high quality are increasingly sought by both consumers and manufacturers [9]. Products from the meat industry are no exception to this rule [10-11], although it is a challenging task since the product exhibits considerable variability of the raw material [12].

The meat industry needs reliable product quality information throughout the production process in order to guarantee high-quality meat products for consumers. Numerous investigations have recently been performed in research laboratories [13] to meet this demand with some success borne out in new technologies for analysing, assessing and certifying product quality. Among the techniques used, those based on physical methods of analysis predominate, with analysis and characterisation systems that often rely on electromagnetic waves [12].

A significant proportion of meat production relies heavily on mechanical refrigeration systems, and indeed very few people can remember a time before refrigeration or when salt was used to preserve meat [14]. Chinese ancestors used to cure and preserve meat using salt since the 13^{th} Century B.C. In the past, the purpose of curing the meat was to reduce spoilage. However, these meats were unevenly cured or dried and were frequently salty [15].

The curing process of the meat is usually controlled by measuring the product's solidity and weight, and the key element is experienced workers with the right instinct [16]. This might lead to human error as workers in large meat companies may not be equally experienced or have the same instincts. Thus, the objective of this study is to investigate a novel method to monitor meat drying process using electromagnetic spectroscopy.

II. MEAT CURING

Meat curing is the application of salt, colour fixing ingredients, and seasoning in order to impart unique properties to the end product [17]. Some techniques involve adding sugar, nitrite, nitrate and sometimes phosphates and ascorbates to meats for preservation, colour development, and flavour enhancement [15].

The functions of the most popular ingredients used in curing are:

1. **Salt**
    a) Provides a characteristic flavour to impart a cured meat taste.
    b) Acts as a preservative through growth inhibition and destruction of microorganisms.
    c) Enhances the transport of other cure ingredients throughout the muscle by osmotic movement of salt itself.
    d) Dehydrates meat tissue to reduce bacterial growth.

2. **Sugar**
    a) Provides a characteristic flavour to impart a cured meat taste.
    b) Counteracts the harshness of salt.
    c) Provides an energy source for microorganisms which convert nitrate to nitrite during a long term cure.
    d) Provides a surface colour characteristic of aged ham if caramelized sugar is used.

3. **Nitrates and Nitrites**
    a) Contribute to the characteristic cured flavour.
    b) Contribute the characteristic reddish-pink colour of cured meat.
    c) Prevent growth of a food poisoning microorganism known as Clostridium botulinum which can occur in foods that require heat processing.
    d) Retard the development of oxidative rancidity and rancid taste.
    e) Prevent warmed-over flavour in reheated products.

Curing materials may be in either dry or liquid form. They will be applied either to the surface of meat or into it by some injection method. The oldest method of curing is dry cure in which the curing ingredients are rubbed on the surface of the meat. The dry, sugar cure method can be used under wider temperature variations and will have less spoilage problems under unfavourable curing conditions [17]. A simple and time-tested dry-curing formula is as follows:

• 8 lbs salt
• 3 lbs sugar
• 2 oz. sodium nitrate
• 1/2 oz. sodium nitrite (or a total of 3 oz. nitrate available; remember, excess nitrite is toxic)

The length of curing is seven days per inch of thickness, for instance, if a meat sample weighs 12-14 lbs and is 5 inches thick through the thickest part, this ham should be cured for 35 days. A two-inch thick belly should cure in 14 days. Another important consideration is to be sure the cure is rubbed into the aitch bone joint and hock end of the ham to avoid bone sour. The temperature range should be high enough for the meat to cure properly and dry, but low enough so bad bacteria and mould doesn't grow. Ideal temperatures for dry-curing are between 10-15 °C [17].

III. WATER ACTIVITY IN MEAT

A. *Definition of water activity*

Water activity (A_w) is defined as the current volume and availability of "free" water in a sample and should not be compared with the water content (*g* water/ *g* substance). A_w ranges between 0 (absolute dryness) and 1 (condensed humidity). Only this component takes an active part in the microbiological growth on the surface which influences the microbiological stability. A_w also has an important effect on the chemical reactions in food [18].

B. *Water activity in meat and meat products*

Water activity is a measure of the energy status of water in a system and predicts which microorganisms will grow in a food. Microorganisms require water of a specific energy level to grow and survive. Microorganisms do not require a specific amount of water to grow (moisture content), which is why water activity and not moisture content is used as a control point to prevent spoilage [19]. Therefore, the water activity is of vital importance for the preserving of foods. There are many techniques and ways to preserve meat products such as cure-drying, freeze-drying and so on, which reduces the availability of moisture to micro-organisms in the product. These methods increase osmotic pressure in food, which means that they lower the water activity [18].

The main benefit of water activity reduction is extension of the shelf life and safety of the meat products. A high water activity in the meat product can cause spoilage or even poisoning as the products are more stable to micro-organisms. Post-slaughter meat has very high water activity as it contains a significant amount of water, with most fresh products containing in the region of 60-75% by weight. Thus, the highest value of the water activity is in fresh meat (A_w>0.99). Dried meat products have a lower water activity because of the water loss during the drying process and salt content [18].

IV. METHODOLOGY

A. *EXPERIMENTAL SETUP*

To complete this experimental work a new electromagnetic patch sensor has been designed and modelled using the High Frequency Structure Simulation Software (HFSS), with the structure designed to be resonant at approx. 2.4 GHz to give sufficient interaction with the water content of meat products, as well as providing a reasonable depth of penetration. Without the latter consideration, the sensor would be prone to misleading results due to rapid surface drying.

The experimental setup comprises a patch antenna mounted on top electronic weighing scales. The sensor is connected to PC via Vector Network Analyser (VNA). Both the VNA and the weighing scales are connected to a computer for data acquisition via a LabVIEW interface, and are placed inside a refrigeration unit to maintain a consistent temperature (approx. 5°C, ± 2°C). A block diagram of the experimental setup is shown below:

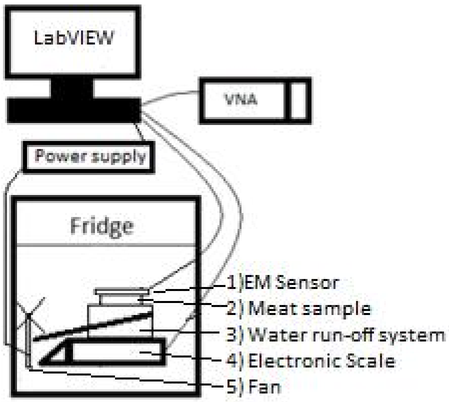

Figure 1 - Block diagram of the experimental setup

A package of four pork loin steaks was purchased from the local Tesco supermarket. A lean piece of steak (fat removed) was cut to a size of 15mm thick, 70mm in length and 50mm wide to cover the conductive area of the sensor. The sample is placed on a bespoke plastic "water runoff system" (shown in Figure 2), designed to prevent water pooling on the weighing scales once lost from the meat.

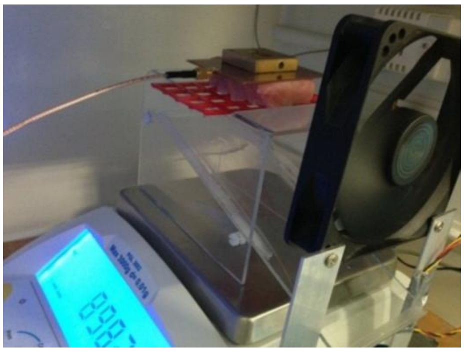

Figure 2 - Experimental setup.

To promote air circulation and promote water loss a fan was fixed inside the fridge. The fan was connected to power supply via a relay (see Figure 3) that is used to switch off the fan while the measurements are taken. The purpose of this is to avoid incorrect weight measurements as the scale is sensitive to small changes in air pressure. The scale was zeroed once the sensor and "water runoff system" were fixed to it, before placing the meat sample.

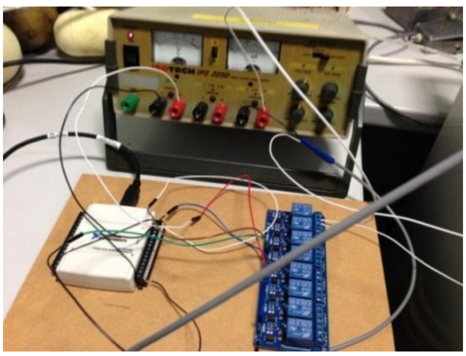

Figure 3 - Power supply and relay to power and control the fan

B. MEASUREMENTS

Measurement from the patch sensor was provided by using the S_{11}-parameter from the VNA since the sensor is single port structure. Data acquisition (i.e. S_{11}, temperature and weight) took place once per hour over a period of 4 weeks. Weight and S_{11} measurement were then correlated to determine the relationship between weight loss of the meat and change in EM signature from the sensor.

.

V. RESULTS

Figure 4 shows the S_{11} measurements, i.e. S_{11} of sample of pork loin steak. The measurements shown in this figure were taken every hour (i.e. 24 times a day) during one week. Measurements of the weight loss of the sample also were taken at the same time during the week (see Figure 5). It can be seen in Figure 4, that there is a noticeable change in EM signature. The change is thought to be caused by the decreasing amount of water in the meat sample. The sample was not touched or moved during the experimental work, and all other conditions, such as temperature and light remained nominally the same during the test. The figure also shows that there is a steady amplitude shift at the frequencies of around 1.5GHz, 2.5GHZ and 3.5GHz.

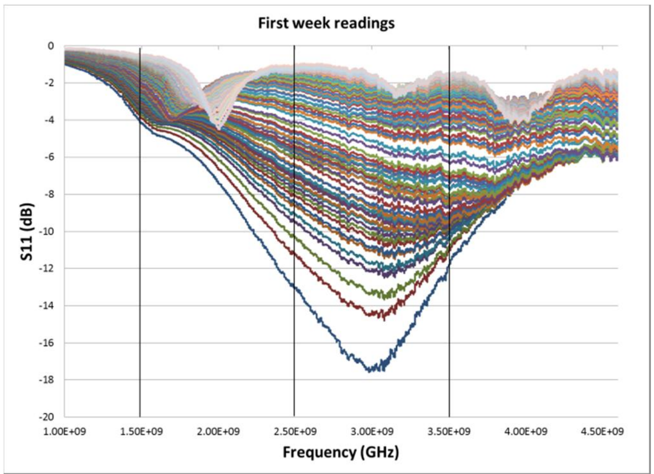

Figure 4 - Readings of EM spectrum taken every hour during one week period

Figure 5 shows that the weight drop of the sample was as steady as the change of the amplitude shown in Figure 4. It can be seen in Figure 4 that there is a larger amplitude shift at the beginning of the week. Figure 5 also shows that there is a slightly larger weight lost in that period of time. This means that there can be a relationship between weight loss of the meat sample and shift of the S_{11} parameter.

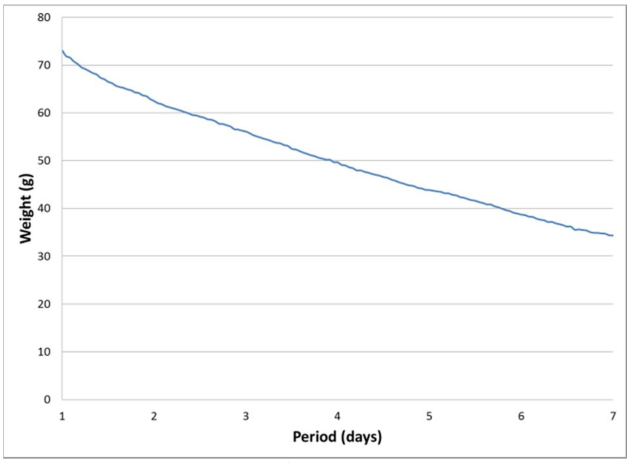

Figure 5 - Weight loss of the meat sample over a week

Figure 6 shows a logarithmic trend line that illustrates weight loss of the meat sample over 4 weeks inside the fridge. It can be seen in the figure, that the weight has a dramatic decrease at the beginning and then, the weight is dropping down steadily. The figure also displays that the data is quite close to the fitted line, where R-squared is 98.6%.

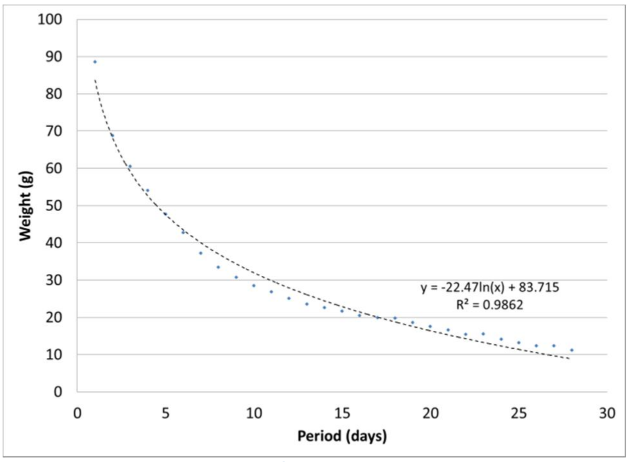

Figure 6 - Weight loss of the meat sample over 4 weeks

VI. CONCLUSION

The objective of this investigation was to monitor the drying process of the meat sample, and identify a relationship between weight loss and change of the electromagnetic spectrum from a patch antenna. A new EM patch sensor was designed and constructed for this investigation. The results showed that a change of the weight loss relates to the change of reflection coefficient. As it was demonstrated in the results section of the paper, there is a dramatic decrease of the weight at the beginning of the drying process. The similar change was noticed in the electromagnetic spectrum from the sensor during that period. S_{11} measurements had greater shift first week and then the shift stabilised so did the weight loss of the meat sample.

Next stage of the investigation will be focusing on a specific range of frequency, between 1.5 GHz and 3.5 GHz. S_{11} measurements at these frequencies can be correlated with the weight loss of the meat sample. Using smaller range of frequency will provide higher resolution data that simplifies analysis of the data.

ACKNOWLEDGMENT

The authors thank Chechen Ministry of Education and Science and Chechen Government for their support during the PhD research. Furthermore, the authors thank the members of the INFORMED EUREKA project consortium for their continued support of LJMU researchers in this application of their sensor technology.

REFERENCES

[1] M. Adous, P. Quéffélec, and L. Laguerre, “Coaxial/cylindrical transition line for broadband permittivity measurement of civil engineering materials,” *Meas. Sci. Technol.*, vol. 17, no. 8, pp. 2241–2246, Aug. 2006.

[2] B. Goy, P. Martin, and J.-M. Leban, “The measurement of wood density by microwave sensor,” *Holz als Roh- und Werkst.*, vol. 50, no. 4, pp. 163–166, Apr. 1992.

[3] L. Gradinarsky, H. Brage, B. Lagerholm, I. N. Björn, and S. Folestad, “In situ monitoring and control of moisture content in pharmaceutical powder processes using an open-ended coaxial probe,” *Meas. Sci. Technol.*, vol. 17, no. 7, pp. 1847–1853, Jul. 2006.

[4] O. Korostynska, A. Mason, M. Ortoneda-Pedrola, and A. Al-Shamma’a, “Electromagnetic wave sensing of NO3 and COD concentrations for real-time environmental and industrial monitoring,” *Sensors Actuators B Chem.*, vol. 198, pp. 49–54, Jul. 2014.

[5] O. Korostynska, M. Ortoneda-Pedrola, a Mason, and a I. Al-Shamma’a, “Flexible electromagnetic wave sensor operating at GHz frequencies for instantaneous concentration measurements of NaCl, KCl, MnCl 2 and CuCl solutions,” *Meas. Sci. Technol.*, vol. 25, no. 6, p. 065105, Jun. 2014.

[6] A. Mason, O. Korostynska, M. Ortoneda-Pedrola, A. Shaw, and A. Al-Shamma’a, “A resonant co-planar sensor at microwave frequencies for biomedical applications,” *Sensors Actuators A Phys.*, vol. 202, pp. 170–175, Nov. 2013.

[7] J. H. Goh, A. Mason, M. Field, P. Browning, and A. Al-Shamma’a, “Using a Microwave Sensor as an Online Indicator of Neurological Impairment during

Surgical Procedures," in *Key Engineering Materials*, 2013, vol. 543, pp. 368–372.

[8] S. Clerjon and J. L. Damez, "Microwave sensing for an objective evaluation of meat ageing," *J. Food Eng.*, vol. 94, no. 3–4, pp. 379–389, Oct. 2009.

[9] W. Verbeke, "Consumer attitudes and communication challenges for agro-food technologies," *AGRO FOOD INDUSTRY HI-TECH*, vol. 22, no. 5. pp. 34–36, 2011.

[10] W. Verbeke, L. Van Wezemael, M. D. de Barcellos, J. O. Kügler, J.-F. Hocquette, Ø. Ueland, and K. G. Grunert, "European beef consumers' interest in a beef eating-quality guarantee Insights from a qualitative study in four EU countries.," *Appetite*, vol. 54, no. 2, pp. 289–96, Apr. 2010.

[11] K. G. Grunert, "Future trends and consumer lifestyles with regard to meat consumption.," *Meat Sci.*, vol. 74, no. 1, pp. 149–60, Sep. 2006.

[12] J. L. Damez and S. Clerjon, "Quantifying and predicting meat and meat products quality attributes using electromagnetic waves: An overview," *Meat Sci.*, vol. 95, no. 4, pp. 879–896, Dec. 2013.

[13] B. M. Abdullah, A. Mason, J. D. Cullen, and A. I. A.-Shamma, "Development of a Predictive Water-Holding Capacity Method in Postmortem Longissimus Dorsi Muscle," 1960.

[14] G. Rentfrow, R. Chaplin, and S. P. Suman, "Technology of dry-cured ham production: Science enhancing art ."

[15] N. G. Marriott, P. P. Graham, and V. C. Extension, *Some Solutions to Difficulties of Home-curing Pork*. Virginia Cooperative Extension, 2000, p. 6.

[16] SWISS MEAT, "Production of Meat Specialties," 2014. [Online]. Available: http://www.schweizerfleisch.ch/en/swiss-meat/handling/production-of-meat-specialties/. [Accessed: 18-May-2014].

[17] F. Ray, "Meat Curing," *Oklahoma State University*. [Online]. Available: http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-2055/ANSI-3994web.pdf. [Accessed: 19-May-2014].

[18] Z. Claudio, "The influence of water activity (aw) in meat products," Lachen, 2008.

[19] DECAGON DEVICES, "Fundamentals of Water Activity." DECAGON, Pullman, 2006.