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THE ESTIMATED POSSIBILITIES OF PROCESS MONITORING IN MILK PRODUCTION BY THE SIMPLE THERMODYNAMIC SENSORS

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ABSTRACT

The characterization and monitoring of thermal processes in thermodynamic systems can be performed using the thermodynamic sensors (TDS). The basic idea of thermodynamic sensor is possible to use in many various applications (eq. monitoring of frictional heat, thermal radiation, pollution of cleaning fluid, etc.). One of application areas, where the thermodynamic sensor can find the new area for a using, is a production of milk products - cheese, yogurt, kefir, etc. This paper describes the estimated possibilities, advantages and disadvantages of the use of thermodynamic sensors in diary productions and simple experiments for characterization and monitoring of basic operations in milk production process by thermodynamic sensors. The milk products are often realized by fermenting or renneting process. Final stages of fermentation and renneting processes are often determined on the base of sensory evaluation, pH measurement or by analytical method. The exact time of the fermentation process completion is dependent on various parameters and is often the company know-how. The fast, clean and simple non-analytical non-contact method for monitoring and for the determination of process final stages does not exist in this time. Tests of fermentation process, renneting process and yoghurt process by thermodynamic sensors were characterized and measured in this work. Measurement of activity yeasts was tested in first series of experiments. In second series of experiments, measurement of processes in milk production was tested. First results of simple experiments show that the thermodynamic sensors might be used for determination of time behaviour of these processes. Therefore, the milk products (cheese, yogurt, kefir, etc.) is opened as a one of new application areas, where the thermodynamic sensor can be used.

Keywords: thermodynamic sensor; fermentation process; yeast

INTRODUCTION

The principle of thermodynamic sensor

The characterization and monitoring of thermal processes in various thermodynamic systems can be performed using the thermodynamic sensors (TDS) that are based on the principle of balance equilibrium. These sensor systems are one of the newer group of sensors for sensing the thermal quantities. The basic idea, basic model and theory of ideal thermodynamic sensor integration as an ideal element in large models of thermodynamic system were presented in patent **(Industrial Property Office of the Czech Republic, 2006)**. The original theory of ideal thermodynamic sensor as a process and media energy activity monitoring device was presented in **Reznicek et al., 2005, Reznicek et al., 2006, Reznicek et al., 2008 and Reznicek, 2014**.

The principle of these thermodynamic sensors is based on measurement of energy, which is supplied to circuit to temperature setting and equilibration of temperature element with ambient. The sensor element is very often integrated with an amplifier and a converter to defined electrical signal (U, I, f), which is very easily connected to other measuring systems.

Three groups of influences have effect on thermodynamic sensors (Figure 1). First group of influences is presented by influences I1. This group have effect only on a temperature of sensitive element T2. Various physical quantities (temperature, radiant heat, humidity, flow of liquid), which are possibly transformed to temperature energy, are theoretically measured in this group.

Second group of influences is presented by influences I2. This group change the temperature properties between the sensitive elements T1 and T2 (difference energy E1 and E2). Volume, density, flow of liquid, pressure and many other quantities can be theoretically measured measure in this group.

Last group of influences is presented by influences I3, which have effect on a temperature of both sense elements T1 and T2. If both sense elements have the same sensitivity, this group does not have effect on output of voltage signal of thermodynamic sensor.

Advantages and disadvantages of TDS

A common feature of thermodynamic measurement system is the monitoring of major events. However, technological windows of production processes are decreasing due to increasing the demands on the reliability and quality of the target product. Accordingly, the demands on the controlling and monitoring increase up to the possibility limit when using current technologies.

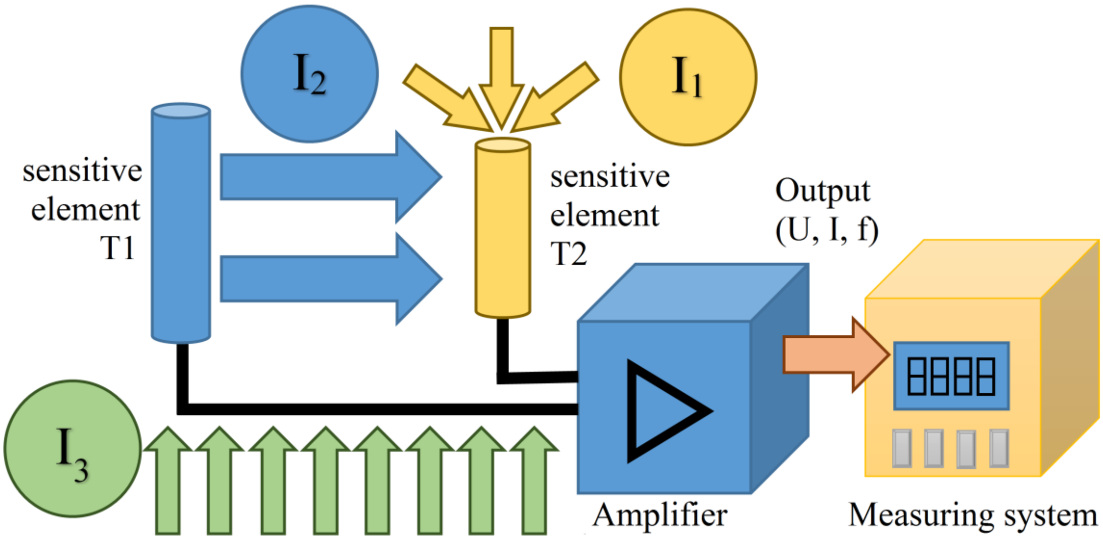

Figure 1 The group of influences I_1, I_2 and I_3, which have effect on thermodynamic sensor.

Therefore, the need for monitoring in area of zero temperature differences and identification of minor events (eg. an unexpected of unwanted event with a small temperature difference) by measurement system increases **(Reznicek, 2014)**.

The using of thermodynamic sensors that are based on the principle of balance equilibrium is one of the ways of monitoring these events on the background of major events (eg. temperature stabilization). Therefore, advantages of TDS are:

- High speed and high sensitivity over other temperature sensors' types, for example thermocouples.
- Possibility of heat flow measuring.
- Directionality of measurements.
- Possibility to process monitoring in zero temperature difference
- Possibility of monitoring and identification of minor events.
- Possibility of easy connect to the control and regulation circuits.

However, TDS also has these disadvantages:

- The system only gives information about the relative temperature changes.
- The measurement is highly dependent on the construction of the measuring system in a specific application.

Therefore, the basic idea of thermodynamic sensor is possible to use in various applications - monitoring of the breakage of glass fibers during their production, monitoring of frictional heat in engine, monitoring reception signal at the antenna, temperature stabilization of the detector nanoparticles, etc. **(Reznicek, 2014)**.

The estimated possibilities of process monitoring in food production by the simple TDS

Many thermal processes exist in food production – cooking, frying, baking, cooling, freezing, sterilization, pasteurization, drying, etc. The TDS can be used to monitor various parameters in many of these processes, which must be very often controlled and recorded for HACCP and customers' certification. It is assumed eg. the possibility to monitor the purity of the oil which is used in frying or monitoring the purity of cleaning emulsion similarly as was tested in project TAČR GAMA – TA01011754 "New methods for the cleaning of assembled substrates with higher effectivity and lower ecological and energy comsumption impact". Because the thermodynamic sensor is very sensitive and fast, it is possible to measure very small temperature changes that may be produced for example by groups of yeast. Therefore, it is possible use TDS in the production:

- dairy products – fermentation processes, yogurt processes, renneting processes,
- breweries – fermentation processes,
- distilleries – fermentation processes,
- control unwanted development of yeast and other microflora (sterilization, canning),
- bakeries –controls vitability yeast,
- pickled cabbage – fermentation processes, etc.

A production of dairy products (cheeses, yogurts, kefirs, etc.) can be one of new application areas, where the thermodynamic sensors can be used. Milk and products from milk are one of important ingredients of food in people´s lives, especially for children. Milk and dairy products are sources of vitamins, proteins, fat, minerals, lactose, etc., which are not fungible in people´s sustenance. The dairy production is composed of complicated and sophisticated processes **(Semjan, 1994)**. These processes are exacting to precision, temperature stability and hygiene. This is a reason for close quality checking.

In the dairy productions, the thermodynamic sensors can continuously monitor, control and regulate the main process parameters – required temperatures and deviations from it (sterilization and pasteurization temperature of milk, dairy products, storage temperature etc.). However, the sensors can also monitor other production parameters, which can be converted to a change of temperature flow – purity and quantity of basic raw materials (milk, marmalade, ...), purity and the amount of auxiliary media (rinsing water, auxiliary gas, etc.), monitoring and control unwanted of unwanted event – sanitizing inspection of manufacturing devices and space, wear down control of production machines etc.

The production of dairy products is often realized by fermenting or renneting processes. The simple clean non-contaction non-analytical method for determination of final process does not exist in this time. Final stages of fermenting or renneting processes are often determined on the base of sensory evaluation or analytical measurements. The different ways to solving these problems are looking for now. One of the possible ways for solution of this problem can be characterisation and measurement of these processes by thermodynamic sensors.

MATERIAL AND METHODOLOGY

Chemicals

Measurement of activity yeasts was tested in first series of experiments. Dried yeast "Instantní Droždí", S. I. Lesaffre, caster sugar "Cukr bílý krystal", Cukrovary a lihovary TTD, a.s., Dobrovice, and distilled water were used as the material for first measurement.

The basic material used for second measurements of milk products was raw milk from farm Farma Hole s.r.o., Velké Přílepy. The yoghurt "White country yoghurt with probiotic BiFi culture", Hollandia Karlovy Vary a.s., Toužim, was used as start culture for production of yoghurt and the rennet proces was made by the reneet Laktochym (1 : 5.000), MILCOM, a.s., Praha.

Experiment

All the measurements were done by using the TDS sensors, which was fabricated in HIT, s.r.o., Nedachlebice. The sensors, a simple measuring circuit, power source and multimeter Metex 3270 D or Almemo 2390-5 (Ahlborn Mess- und Regelungstechnik GmbH, Germany) as voltmeter, which was controlled by computer, were main parts of workplace. The workplace for experiments with thermodynamic sensors is shown on Figure 2.

Temperature was 25 °C in case of first experiments with water and 35 °C in temperature-controlled box in case of second experiments with milk products.

Statistical analysis

The data were analysed using software Excel 2013 (Microsoft Corporation, USA) and the results were expressed by graph. Each experiment was measured at least three times and the resulting curve was calculated as the mean value of these measurements.

RESULTS AND DISCUSSION

Measurement of activity of yeasts was tested in first series of experiments. Experiments were made with water in room temperature (25 °C). Volume of water was 25 mL. First experiment **(Figure 3)** was focused on fermenting process, where the yeasts weight was changed. The test weight was 0.1 g, 0.5 g, 1 g and 1.25 g. Weight of sugar was 1 g. Results show a dependence of yeasts activity on yeasts weight in first fermentation phase and stabilization of yeasts activity on constant value in second phase of process. The initial weight of the yeast affects the increase rate of the total yeast's activity. It is assumed that increase of the yeasts number affects heat flow between elements T1 and T2 (influence I2). Next, increase of the number of active yeasts increases a heat, whitch coming to the element T2 (the effect I1). After reaching a maximum, the number of active yeasts decreases, therefore the heat coming to the element T2 is also reduced. The weight of sugar was changed (0.5 g; 1 g; 1.25 g) in next experiment (Figure 4). Weight of yeasts was 0.3 g. The yeasts activity is increased with weight of sugar in first fermentation phase and is stabilized on constant value in second phase of process again.

Viable yeast can be used as an inoculum for many fermentations processes in the food industries. The fermentation process increases the total value of the fermented foods, eq. improving the quantity and quality of proteins and their accessibility, increase the digestibility of starch, increasing the content of vitamins, especially group B (riboflavin, thiamine, niacin, folic acid), increase the availability of mineral elements, etc. **(Arora, Jood and Khetarpaul, 2010; Charalampopoulos et al., 2002; Rivera-Espinoza and Gallardo-Navarro, 2010; Kocková and Valík, 2011)**.

Traditionally, yeast viability has been measured in colony-forming units after plating of cells on growth medium or by direct microscopic counting using dye exclusion methods **(Jones, 1987a, b; Fung, 1994; Lloyd and Hayes, 1995; Haugland, 1996)**. Next measurement of yeast viability can be made a flow cytometry **(Deere et al., 1998; Attfield et al., 2000)** or monitoring CO_2 as product of yeast activity. For yeast identification, PCR-RAPD and RFLP-PCR methods **(Drozdz et al., 2015)** can be used. These methods can be used for determination of yeast grow curve. The grow curve of yeast **(Halasz and Lasztity, 1990; Walker, 1998; Neal, 2004)** and measured curves for fermenting process of yeasts in water with a change of yeasts weight have a very similar character. In accordance with the weight of the inoculum, the measured voltage measured voltage is increased and stabilized after some time. Similarly, the character of the measured curves for fermenting process of yeasts in water with a change of sugar weight is also in accordance with the present character of growth curves.

In second series of experiments, measurement of processes in milk production was tested. Experiments were made with raw milk in temperature-controlled box (35 °C).

Figure 5 shows a characterisation of yogurt process. Start and final stage of this proces is demonstrated. In the yogurt production, a mixed base startet yoghurt culture with the bacterial strain *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus salivarius* subsp. *thermophilus* added to the milk. Both living organisms must be in a product in the optimal ratio. *L. delbrueckii* ssp. *bulgaricus* partially degrades the casein. This releases valine, histidine, methionine, glutamic acid and leucine, which are stimulating the growth of *Streptococcus salivarius* subsp. thermophilus. Streptococci forms lactic acid and creates favorable conditions for the growth of lactobacilli **(Courtin and Rul, 2004; Walstra, Wouters and Geurts, 2006)**. It is possible to find a hint of two peaks on the curve of yogurt process on Figure 5. These peaks can be assigned activity lactococci and streptococci in the starter culture. End of measurement can also be influenced by a change the viscosity in the final stage of the process. The example of rennet process measurement is shown on Figure 6.

Figure 2 The workplace for experiments.

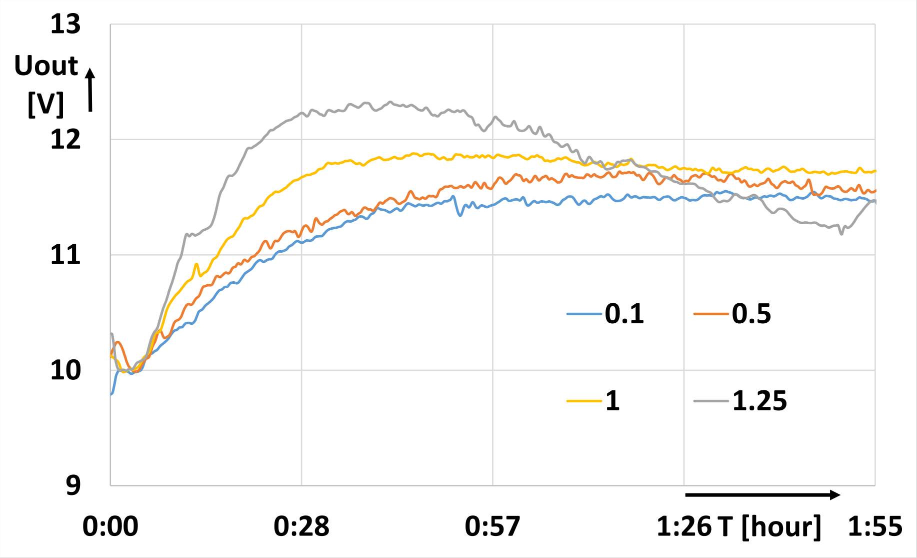

Figure 3 The fermenting process of yeasts in water - a change of yeasts weight.

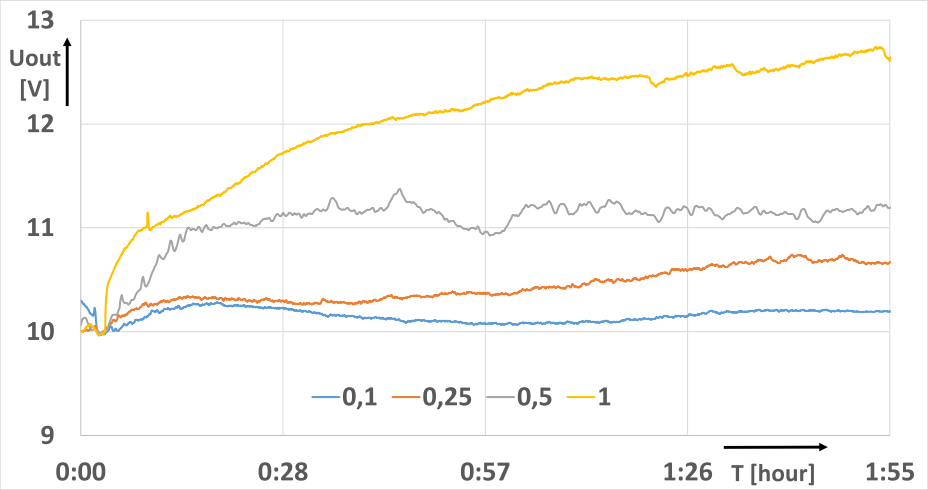

Figure 4 The fermenting process of yeasts in water.

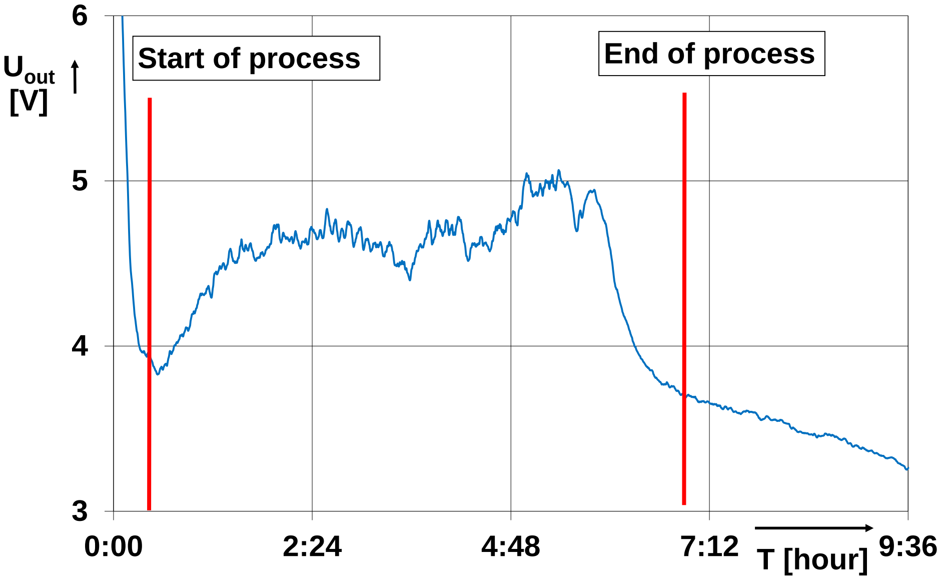

Figure 5 The yogurt process.

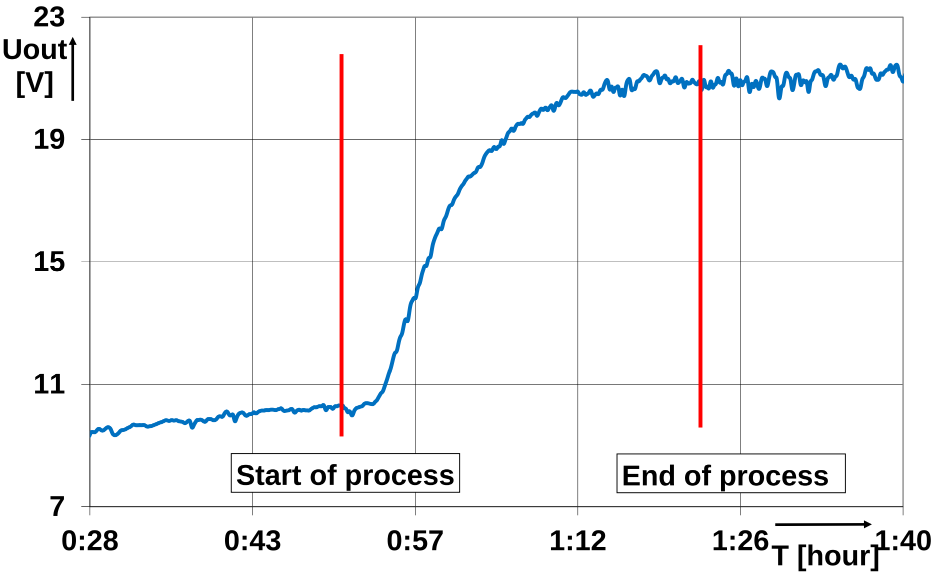

Figure 6 The rennet process.

The final stage of this proces is demonstrated again. The measurement is influenced by a change the viscosity, which have impact to termal properties of yogurt. After adding rennet (very often with chymosin enzyme) to milk, the casein micelles start to aggregate and forming a gel **(Walstra, Wouters and Geurts, 2006)**.

Because this is a new area of application of TDS and new method of measurement, it can not yet compare the results with other authors. Results can only be estimated in comparison with standard methods, which are less flexible and time and material consuming.

Although the number of measurement repetition was low, the first results show a possibilities TDS in monitoring of yeast activity in fermentation processes and determination of final stage in yogurt and rennet processes.

CONCLUSION

The thermodynamic sensor was tested in basic operations in milk production. Tests of rennet process, yogurt process and fermentation process were characterized and measured with thermodynamic sensor, which was borrowed from HIT, s.r.o. First results of simple experiments show that the thermodynamic sensors can be used for time behavior and end determination of this processes.

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