Economic evaluation and design of control mechanisms to determine the concentration of juices

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Abstract: There is a significant attention paid to food analysis in the context of authenticity monitoring in the food industry. Although this has focussed increasingly on food safety and authenticity, the agro-food sector has also instituted requirements for the product identification, differentiation and historical monitoring. For the design and evaluation of the control mechanism, here is used the common approach for the design of experiments (DOE), specifically the "full factorial" design. The uniqueness of the solution lays in a geometric interpretation of the large variability the impedance, due to the samples provided by different producers. The presented solution consisted of the linearization variable zone by the Taylor polynomial. In the next step, there was conducted fuzzification of the electric impedance to determine the mechanism for identifying of juice concentrations.

Key words: control mechanism, design of experiments, electrical impedance, food quality, net present value

The electrical impedance spectroscopy (EIS) has a notable potential in the food analysis applications. From the practical point of view, the EIS is able to find the material properties of organic materials, such as the phase change, the ion concentration, the water transfer and the water content (Kitamura et al. 2008).

For instance, it can be used for the authenticity checks of foods, such as fruit juices. The most frequent cases of adulteration involve a reduced fruit component compared to the declared amount on the label (i.e. the higher water amount can be determined using EIS because the impedance grows with the water content). Very often, the product is incorrectly marked as the '100% juice', when in fact the concentrate content is lower and the reconstitution is generated using a lower quality water. Added sugars and acids are excellent camouflage media, for instance, when replacing the expensive orange juice concentrate with a cheaper grapefruit one. In addition, the so-called pulp wash can be used, although this is not allowed in the EU. In the United States, a maximum of 10% of the content can be added.

The EIS is a non-destructive measurement method used on a long-term basis for the measurement of the corrosive changes in metal materials (Laska 2002) and changes in biological materials (Sanchez 2009); lately, its use has increased in other sectors like the food industry. In this context, the EIS is probably most used for the microorganism detection that is for investigating the food contamination when controlling safety or evaluating the presence of undesirable microorganisms, primarily *Escherichia coli*, *Salmonella*, *Cronobacter* (Laczka et al. 2011), *Staphylococcus aureus* and *Campylobacter* (Wu 2005). The technique is employed for the detection of the production quality, input testing during production as for instance oxygen and partially deionised water (Ayliffe et al. 1999), as well as monitoring the production technology of, for example, dairy products like cheeses (Mukhopadhyay 2010).

The advantages of the EIS are that it is relatively quick, simple and non-invasive. Among other things, it enables us to obtain a quick chemical-physical information on a large amount of samples and then to decide which of them will be analysed in detail. In this way, it can save a lot of cost for the analytical laboratories.

The main disadvantage is the difficulty of the EIS method to the evaluating mechanism of the conductivity measured data. The data show a significant variability, which is caused by the differences in inputs into the production process at the individual

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producer (Hron et al. 2014). Therefore, our aim was to develop such a control mechanism that would be robust (insensitive) to the variability of the input data reactance (or impedance) and would be able to reliably determine the concentration of a substance in a non-invasive method. Furthermore, it should be an economically profitable device. For that, we used the geometric interpretation, the Taylor polynomials, the fuzzy logic approach and the factorial designs in the design of experiments (DOE).

Over the last 15 years or so, the DOE has gained an increased acceptance in the USA and Japan as an important component for improving the process capability, driving down the quality cost and improving the process yield. In Europe, this approach is not as much widespread yet. Nevertheless, a number of successful applications of the DOE for improving the process performance, the product quality and reliability, reducing the process variability, improving the process capability, developing new products, etc. have been reported by many manufacturers over a decade (Albin 2001; Antony 2001).

The EIS includes the measurement and analysis of materials with dominant ion conductivity. Such materials are solid and liquid electrolytes, melted salts and ion conductive lenses, as well as polymers and non-stoichiometric ionically bound single crystals, where the conduction may include the movement of free space ions (grid) and partially the bound ones. The analysis is usually carried out at a certain frequency level, although the measurements are sometimes performed in time sections and then the measurement is transformed into a frequency area. The EIS is not limited only to the measurement and data analysis on the impedance levels (for example, impedance vs. frequency), but it may include any of four basic levels (Macdonald 1992). Currently, there are several examples of the experimental use Electro-chemical Impedance Spectroscopy (EIS). For example (Zia 2013) used the EIS to the conjunction with the fabricated sensor to detect phthalates in the de-ionized water. Or the resistance-in-series models can also be used to analyse the flux behaviour, which involved the resistances of the membrane itself, the fouling and solute concentration polarisation (Baklouti et al. 2013). Ahmad et al. (2013) provided a study of the effects of using different types of the whey protein isolate (WPI) powders with different fat concentrations on the surface concentrations and the morphology of spray-dried powders and on the yields of powders from spray drying. Bilyy et al. (2012) published a new analytical method of a high-selective detection of mycotoxins in food and feed are considered. The principle of this method is based on the optical registration of the changes of the conduct of the electric polarized bacterial agents in the solution at the action of the external gradient electric fields. Another possible application is the analysis of the differences between the organic food and conventional food. Organic foods are grown using the principles of organic agriculture that are produced, processed and packed without using chemicals (Kutnohorska and Tomsik 2013).

In terms of the EIS procedure, the voltage is introduced to an electrode and the subsequent current response is measured according to the Ohm's Law; thus, the system resistance is measured, but because the alternate voltage is used, the system resistance is variable with the frequency, and this is marked as the impedance. The impedance can be explained using complex numbers and has two components, the real and imaginary parts, which vary with the frequency.

The electrochemical impedance is usually measured using the AC current potential, for instance, in a cell, and then the current carried through the cell is measured. Let us assume that we have applied a sine potential excitation. The reaction to this potential is the AC current signal. This current signal may be analysed as a summary of the sine function (Fourier series). It is displayed in the form of the movement within the phase (Orazem 2008). The impedance is a complex quantity which consists of the real (resistance) and imaginary (reactance) components and it is linked with the qualitative parameters of samples. A specific impedance spectrum is dependent on the on frequency (*EIS*), as well as on the structure and chemical composition of the samples. In terms of the chemical composition of water, mineral substances, organic salts and their dissociation play an important role. The impedance is therefore a complex physical value expressing the sine tension phasor ratio to the sine current phasor passing between two points. Both the current and tension are phase-moved. The impedance is marked as the phasor Z and its unit is Ohm [Ω]. In the Cartesian coordinate system, it is defined as follows:

$$Z = R + j \times X = Z \times \cos\phi + j \times Z \times \sin\phi \qquad (1)$$

where the real part R is the resistance and the imaginary part X is the reactance.

The real part may be linked with the resistance in a tissue, that is, the cytoplasm and symplasts (intercellular joints between the neighbouring cell cytoplasms which let water and some other substances through). In contrast, the imaginary part is linked to the capacitance; it depends on the frequency and inductive reactance. Moreover, it includes the cellular integrity and dielectric properties of the material (Macdonald 1991; Chevalier et al. 2006; Wu et al. 2009; Li et al. 2009).

MATERIALS AND METHODS

For the design of experiments, conducting and measurement, an impedance analyser (Agilent 4294A Precision Impedance Analyzer, Agilent Technologies Japan, Ltd.) was used with a 4-TP adaptor. We measured under the following conditions: voltage amplitude range 0.5V–2V, frequency range 40 Hz–1 MHz, constant laboratory temperature.

In the following, the impedance results in different concentrations of orange juice are shown. The concentrations were 33%, 50%, 66%, and 100%. It was confirmed that the highest impedance was reached by the adulterated juice at a 33% concentration. In contrast, the lowest impedance was obtained in the pure juice, which exhibited the highest conductivity.

It is interesting that the particular juices do not show the same values under the application of identical frequencies. We assume that this results from different production technologies and the use of concentrations of various proveniences. In other words, the use of different types, respectively quality of water and different composition of additives during the production results in different impedance values. The main objectives of this article were to identify such differences and to design an evaluation mechanism which would not be sensitive to the impedance change at the same frequency due to the different juice producers.

Table 1 shows the average impedance values of the file data from seven juice producers. This table shows a very slight dependence of the impedance variable on the frequency of the electric current. In addition, the table shows a strong dependence of the impedance variable on the fluid concentration. The lower part of the table shows the relatively constant differential impedance changes at the frequency, expressed as a dependent variable in the concentration. This means that the impedance is relatively insensitive to the change in the frequency, as well as the frequency differentiation according to the concentrations of the substance.

As can be seen from Figure 1, the impedance measured values have a certain range, which is represented from 100% to 33% juice concentrations from different producers at the constant frequency. This range size (intervals of values belonging to output concentration) can be definitely allotted to a certain set through the use of the fuzzy set simulation.

The designed system of the controlling mechanism is described in the figure below. It is clear that the impedance difference between the concentrations 100% and 50% concentration is sufficiently large (or the interval width is sufficiently small) for a clear differentiation. That means that the 100% fuzzy set does not have any intersection with the 50% fuzzy set. This is an important information for the customs offices in terms of the duty assessment when it comes to checking concentrations. For monitoring of the food quality, however, this is not helpful, and thus it is necessary to refine the fuzzy sets. A

Table 1. Mean impedance values for different frequencies and different concentrations of juice

Frequency (Hz)	Mean of the real part of impedance (Ω) for a given concentration (%)			
	100% concentration	66% concentration	50% concentration	33% concentration
100	189.34	249.16	299.27	493.05
200	188.18	248.05	298.06	491.66
300	187.76	247.65	297.62	491.19
1 000	186.99	246.88	296.79	490.32
10 000	186.28	246.23	296.05	489.41
100 000	186.04	246.07	295.90	491.78
At frequency	Difference of impedance (Ω) for different concentrations of juice			
F =1 kHz	59.82	50.11	190.78	
f =0.3 kHz	59.89	49.97	193.57	

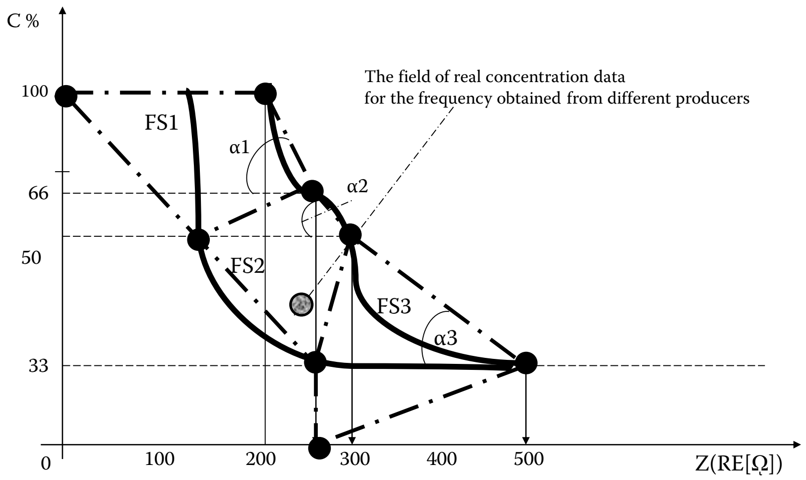

Figure 1. Graphical decomposition of zone data to the concentrations of fuzzy sets

set corresponding to 75% concentration was added for this purpose.

For the deduction of the exact values, it would be suitable to use Figure 1. It is clear from this that certain values of the measured impedance relate to certain intervals of the juice concentration. The system starts to stabilise from the concentration of 33%. The lower range limit may represent a lower specific limit expressing the quality of the food – in this case, the minimal value of the guaranteed juice content in the product. In terms of frequency, it was shown that this does not have a substantial influence on the range of the measured concentration values.

Transformation of the real part of impedance Z (RE) to the relative coordinate is based on Figure 1. From this graph, it can be seen that if the concentration is not less than 33%, the range of input values of the real part of the impedance is 492-0. Geometrically, we can interpret the slope of the edge of the zone, depending on the concentration of the real component of the impedance Z (RE) as the tangent of the incident angle at the base of the quadrangle. For each quadrilateral, separate fuzzy sets will be created:

$$\tan\alpha = \frac{\Delta C}{\Delta Z(RE)} \tag{2}$$

The slope of the edge of the zone of concentration, which is between 66% and 100%, is calculated as follows:

$$\tan\alpha 1 = \frac{\Delta C1}{\Delta Z(RE)1} = \frac{100-66}{249-189}\left[\frac{\%}{\Omega}\right] = 0.7333\left[\frac{\%}{\Omega}\right] \tag{3}$$

Analogously, we determine the slope edge of the zone of concentration between 50% and 66% or between 33% and 50% as follows:

$$\tan\alpha 2 = \frac{\Delta C2}{\Delta Z(RE)2} = \frac{66-50}{298-249}\left[\frac{\%}{\Omega}\right] = 0.3265\left[\frac{\%}{\Omega}\right] \tag{4}$$

$$\tan\alpha 3 = \frac{\Delta C3}{\Delta Z(RE)3} = \frac{50-33}{492-298}\left[\frac{\%}{\Omega}\right] = 0.0888\left[\frac{\%}{\Omega}\right] \tag{5}$$

We can determine the real concentration after the determination of fuzzy sets, and gradients of the individual zones. The concentration is always determined for a specific fuzzy set, FSi. For example, if we decide (according to Figure 2) that the value of Z(Re) belongs to the set of FS1, we determine the value of the concentration of juice CH as a linear increase of $\Delta c1$ to the top of the standard concentration value of the set FS2 (C66); thus:

$$C_H = C66 + \Delta c_1 = C66 + \tan(\alpha_1) \times \Delta R_1 \tag{6}$$

where $\Delta R1$ is the difference of reactance (the real part of impedance) between the measured value (Rmeasured) and the standard value (Rstandard) for the FS1 fuzzy set.

Equation (6) can be generalised to determine the concentration of a fuzzy set:

$$C_i = C(FSi) + \tan(\alpha_i) \times [R_{\text{measured}} - R_{\text{standard}}] \tag{7}$$

If we want to generalise solutions for the general form of the concentration of certain substances in food depending on the electric impedance, we need to move from the tangent to the differential expression. In this case, the application of a nonlinear mathematical model is limited by the complexity of solving the mathematical equations of the system. However, for a rough determination of the juice concentration, we can carry out the linearisation of the original nonlinear model in order to obtain a linear one, which is close to the reference point of the fuzzy set. This progress is usually sufficiently accurate for the description of the behaviour of the 'impedance-concentration' system, and it further allows us to obtain an analytical

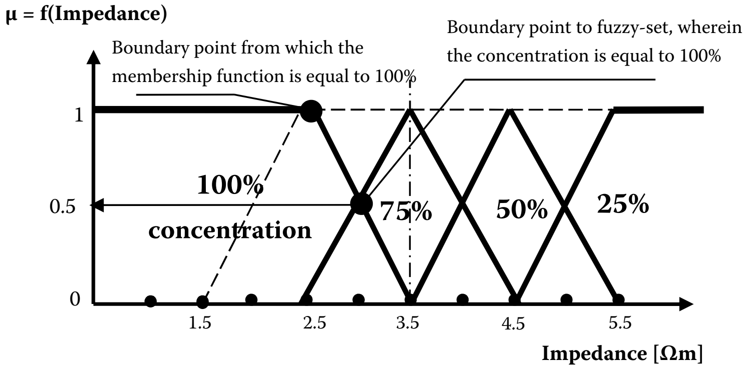

Figure 2. Fuzzification of the response – the juice content concentration

solution from the system of equations. For linearisation, the Taylor polynomial is commonly used in the vicinity of the boundary fuzzy sets, which are the only linear members, while the others are neglected. This linearisation has the following form:

$$Ci = C(FSi) + \sum_{i'1}^{n} \left(\frac{\partial f}{\partial R_i} \right)_0 \times (R_i - R_0) \tag{8}$$

where the coefficient $\left(\frac{\partial f}{\partial R_i} \right)$ denotes the partial derivative of the function *Ci = f (R1, R2, ..., Rn)* with respect to *Ri*, and subscript '0' indicates that the measurements were carried out in the steady state (in the aftermath of the transition state of response).

Finance evaluation of investments in the development of facilities for determining the concentrations

For the economic evaluation, we used the net present value (NPV).

The internal rate of return (IRR) is generally considered inferior to the net present value (NPV) as a tool for evaluating and ranking projects, despite its inherently useful comparability to the cost of capital and the return of other investment opportunities (Weber 2014). Therefore, we preferred the method of NPV for the economic evaluation of the profitability development and the sales control mechanism, which can be used for the Electrical Impedance Spectroscopy in those cases where there is a large inconsistency in the measured data.

From the financial point of view, the NPV or net present worth (NPW) of a time series of cash flows, both incoming and outgoing, is defined as the sum of the present values (PVs) of the individual cash flows of the same entity. The NPV can be described as the 'difference amount' between the sums of the discounted cash inflows and cash outflows. It compares the present value of money today to the present value of money in the future, taking the inflation and returns into account.

Generally, the NPV is determined by the formula:

$$NVP = CFS - IN \tag{9}$$

where IN is the total investment costs, and CFS represents the present value of cash flows.
The PV of cash flows is determined by the sum of the cash flows in each year adjusted using the real discount rate of decline in nominal values:

$$CFS = \frac{CF_1}{(1-r)} + \frac{CF_1}{(1-r)^2} + \cdots + \frac{CF_n}{(1-r)^n} \tag{10}$$

where *r* is the interest rate, *CFt* is the cash flow in the time (*t*) period from 1 to 6.

Investment projects whose *NPV* is greater than or equal to 0 are acceptable in terms of economic profit.

Cash flows in each year can be determined using the following calculation scheme:

[1]. (+) = 1.06 RETURNi – 1 × $p \times q$+ other income [CZK]
[2]. (–) Ve = 1.06 – 0.65 × 1 $p \times q$ [CZK] .... variable costs
[3]. (–) = 1.06 FNI – 1 × 8 106 [CZK] .... fixed costs
[4]. (–) AMORTISATION [CZK]
[5]. ZPDi = RETURNi – VNI – FNI –
DEPRECIATIONi [$] ... profit before tax
[6]. TAX = 0.4 × ZPDi
[7]. BTI = ZPDi – TAX ... net profit
[8]. CFi = BTI + AMORTIZATIONi – D TRAY i;
i – 1 [CZK] ... cash flow (cash flow) in the
i-th year

where:
i = the year order of manufacture, $i \in \langle 1; 6 \rangle$
p = the average price of a sold piece (CZK/unit)
q = total quantity of products sold (unit)

The supply of the material in the *i*-th year of production is:

[9]. $SUP_i = SUP_{i-1} + \Delta SUP_{i;i-1} =$
$SUP_{i-1} + 0.12 \cdot (RETURN_{i+1} - RETURN_i)$

Table 2. Economic evaluation of the in production facilities to determine the concentration of juices (in million CZK)

Balance sheet CF	Year of production					
	2015	2016	2017	2018	2019	2020
Revenues	55.000	58.300	61.798	65.505	69.436	83.945
Variable costs	35.7500	37.895	40.168	42.578	45.133	47.841
Fixed costs	8.0000	8.480	8.988	9.528	10.099	10.705
Depreciation	2120	3.440	3.440	3.440	3.440	3.440
ZPD	9.130	8.485	9.200	9.958	10.762	21.957
Tax	3.652	3.394	3.680	3.983	4.305	8.583
Net profit	5.478	5.091	5.520	5.975	6.457	13.374
Inventory	6.996	7.415	7.860	8.332	8.832	8.832
Changes in inventories	0.396	0.419	0.444	0.471	0.499	0.000
CF	7.202	8.111	8.515	8.943	9.397	16.814
CFS =	47.123					
Investments =	19.200					
Inventory in early 2015	6.600					
NPV =	***+21.323***					

The net present value of the investment is positive (profitable) for the planned duration of the patent, therefore, the development of the mechanism for determining the concentrations of juice without the need for the chemical analysis is economically convenient.

CONCLUSION

The EIS has a notable potential in the food analysis applications. For instance, it can be used for the authenticity checks of foods such as fruit juices. The most frequent methods of adulteration are reducing the amount of fruit to a declared amount on the label (i.e. the higher water content can be determined using the EIS, as with the growing water content, the impedance also increases). Very often, there is also incorrect marking of the product as '100% juice' when in fact the concentrate content is lower and a reconstitution is carried out using a lower quality water.

The use of this method is appropriate in terms of the lower cost of detecting concentrations in juices, as well as the speed of the detection response. Thus, the EIS could be used for the customs administration. The next phase of the research is to include more advanced methods such as the response surface methodology (RSM) by adding other variables such as the voltage, chemical reagents and so on. By adding other variables, we can obtain the optimal response, namely the narrowest field of the impedance values from different producers of the investigated food (juices, in this case).

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