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APPLICATION OF VANE IMPELLER FOR ASSESSMENT OF RHEOLOGICAL PROPERTIES OF POULTRY LIVER PATÉ

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A b s t r a c t. Rheological properties of market-available liver paté spreads were investigated using a vane impeller (d = 20.5 mm, h = 41.6 mm) and the drive system of a rotational rheometer Rheotest RV2. The measurement of the shear stress σ, developed on the walls of the cylinder, formed by the vane rotation, enabled evaluation of the static yield stress σ_y and flow curves of the samples tested. The measurements were carried out at temperatures of 10, 15, 20 and 50°C. The spreads tested displayed variable water content over the range of 65.0-69.7 g (100 g)$^{-1}$ and fat content from 10.7 to 20.6 g (100 g)$^{-1}$. Static yield stress value σ_y of the samples varied from 45 to 130 Pa and depended upon the sample and temperature. The flow curves were typical for shear-thinned fluid possessing yield stress, and suggested good agreement with the concept of so-called ideal spread. This term means a material possessing yield stress sufficient to keep its shape under its own weight while simultaneously displaying relatively low apparent viscosity. Over a wide range of shear rates $\dot{\gamma}$ the relationship $\sigma(\dot{\gamma})$ was linear and for its approximation the Bingham equation could be applied. The experiments have shown significant viscosity differentiation between the spreads obtained by various manufacturers, and applicability of the vane impeller for spreadability evaluations.

Keywords: liver paté, plastic viscosity, vane rheometry, yield stress

INTRODUCTION

Specific rheological properties are expected from products, the special textural property of which is spreadability, usually comprehended as characteristic subjectively evaluated by a consumer. In production practice, however, there is a need for objective determination of spreadability of multiple food products by means of contemporary rheometric methods. Bearing in mind the complexity of rheological properties of food products and possibilities of their characterization with numerous rheological parameters, in the case of the discussed group of products worthy of notice is the possibility of measuring yield stress (Steffe 1996). It is especially important, since on the one hand such a product is expected to be firm enough and not to change the shape under its own weight, whereas on the other hand – when constrained to flow under shearing, it should be easy to spread on a piece of bread, for instance (Prentice 1984). Such expectations correspond with the concept of a fluid possessing yield stress. Below the stress described as yield stress σ_y, such a material behaves like a solid body; whereas exceeding the σ_y value leads to irreversible deformation i.e. flow, which enables spreading the product over a surface.

Though some authors question the existence of the yield stress as a physical value (Barnes 1999, Steffe 1996), undoubtedly it is a measurable property that facilitates the classification and characterization of a number of raw materials displaying visco-plastic behaviour. In such an interpretation of the yield stress, however, of key significance is specification of the method of its determination. A common method involves the application of extrapolation of flow curves approximated with the rheological models of Bingham, Herschel-Bulkley and Casson (Steffe 1996). In this case, however, achieving the correct results requires corrections of shear rate taking into account geometry of the measuring system and properties of medium being the object of the study (Rieger and Zander 2007, Zander and Kiljański 2007).

The absolute value of yield stress may be determined in the case of creep test / stress relaxation and stress growth conducted with the use of classic rheometric systems (Lidell and Boger 1996, Stokes and Telford 2004). A significant inconvenience of the application of classic rheometric sensors is the necessity of inducing a sample’s flow in a narrow gap. In the case of multi-phase materials, the relation of the size of dispersed phase particles to the gap size and wall slip effects are, however, a source of errors (Barnes 1995, Tabuteau *et al*. 2004). A solution to this problem may be the application of impellers as measuring sensors and the use of their power characteristics in the area of laminar agitation (Stręk 1981, Kemblowski and Kristiansen 1986).

A vane impeller with 4-8 straight blades mounted on a shaft of small diameter has been extensively used as an element of direct measurements of yield stress. Initially, it was applied in assays of mechanical properties of soil and turned out to be a very convenient tool for measurements of the yield stress of concentrated systems, e.g. cements, kaolin, suspension of minerals, bentonite gels, volcano lava and wax oils (Barnes 1999, Lidell and Boger 1996).

The principle of yield stress measurements by means of a vane impeller is based on the assumption that shearing stress induced by the vane rotation acts evenly on the side surface and extreme planes of a rotational cylinder constituted by the examined material entrapped between the vanes of the impeller (Nguyen and Boger 1983). The validity of this assumption has been confirmed both experimentally and analytically by computer simulations (Yan and James 1997).

A number of reports have been published on the possibility of applying this type of impeller for the evaluation of the rheological properties of food products. Briggs *et al.* (1996) applied such an impeller for the assessment of consistence of ice cream. Its applicability has also been demonstrated for assaying the rheological properties of cottage cheese (Zander *et al*. 1999), flavouring additives to dairy products (Zander *et al*. 2006b), cosmetics and a variety of other heterogeneous systems (Stokes and Telford 2004). Daubert *et al*. (1998) used this type of measuring sensor while determining the spreadability of 13 food products and showed that this textural characteristic was strongly affected by the yield stress. The technique discussed was also used in measurements of yield stress of such products as: mayonnaise, chocolate, salad sauces, apple and tomato pulp (Daubert *et al*. 1998) as well as cheeses (Truong and Daubert 2001). The popularity of this measuring method results from the simplicity of sample preparation and conducting measurements, the possibility to perform measurements directly in the container and minimal disruption of the structure of the material examined once the impeller has been immersed into the sample (Briggs *et al*. 1996, Barnes and Nguyen 2001, Truong and Daubert 2001). Recently, this method has been standardized in the evaluation of the yield stress of food products (Barnes and Nguyen 2001). Moreover, it has been demonstrated that the applicability of the discussed type of impellers is not limited to single-point measurements of the yield stress only, but also enables more advanced rheological characteristics of the media to be examined (Glenn *et al*. 2000).

The objective of this study was to evaluate the possibility of obtaining rheological characteristics of commercially-available liver paté samples based on the results of measurements of torque occurring on the shaft of a vane impeller.

EXPERIMENTAL

Commercially-available liver paté samples originating from three different producers (series of samples denoted with letters A, B and C) were examined. The water and fat contents in the samples were determined according to Polish Standards: PN-ISO 1442:2000 and PN-ISO 1444:2000, respectively.

The evaluation of rheological properties of the liver-paté samples examined was conducted by means of a vane impeller (d = 0.021 m, h = 0.042 m), using the drive and torque measuring system of a rotational rheometer Rheotest RV2. A schematic sketch of the impeller used is presented in Figure 1.

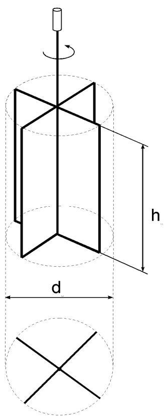


Fig. 1. Vane impeller used as the rheometric sensor in the experiments

As the container being filled with the liver paté examined, a thermostatic, stainless steel cylinder of an internal diameter of D = 0.040 m was used. In the experiment, the rotational speed N of the impeller was changed stepwise over the range of $4.6 \cdot 10^{-3}$ to 2.5 s^{-1}. Simultaneously, torque M was registered in 1 sec intervals using a Metex M-3640d milivoltmeter.

In Figure 2 a typical course of changes in the torque during the first rotation of the impeller is depicted. The maximum value of torque M_{max} occurring during the first rotation of the impeller at the rotational speed of $N = 4.6 \cdot 10^{-3}$ s^{-1} was taken as a measure of static yield stress of a sample, σ_y, which was computed from the equation (1) given by Nguyen and Boger (1983) and Barnes and Nguyen (2001):

$$\sigma_y = \frac{2M_{\max}}{\pi d^3}\left(\frac{h}{d} + \frac{1}{3}\right)^{-1} \tag{1}$$

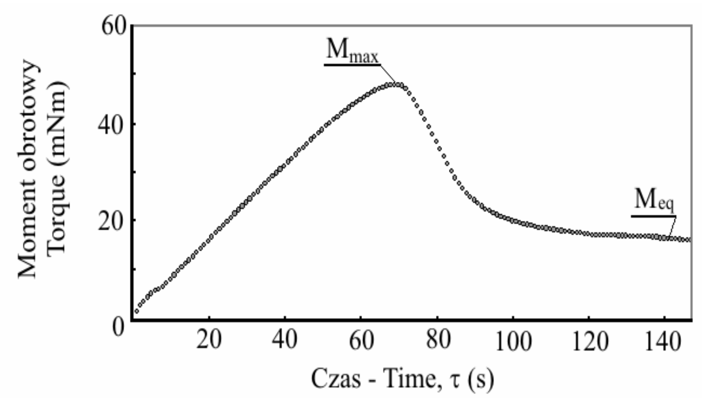


Fig. 2. Typical course of torque changes during the first rotation of vane immersed in the sample tested

Equilibrium values of torque M_{eq} (Fig. 2) at each rotational speed was assumed to be a measure of shearing stress σ occurring on the surface of the rotating cylinder formed from the sample of the material examined. All measurements of rheological parameters were carried out at temperatures of 10, 15, 20 and 5^{o}C.

A statistical analysis of the measurement results and estimations of regression equation parameters were performed by means of Statistica *8 PL* software (Statsoft, Inc. 2007).

RESULTS AND DISCUSSION

The characteristics of the material analysed are presented in Table 1. It shows that the samples of liver paté used for rheological measurements differed both in raw material composition and proximate chemical composition even though they were found alike in consumer evaluation. The samples examined were characterized by some variation in water content over the range of 65-69.7 g (100 g)$^{-1}$ as well as in fat content over the range of 10.7-20.6 g (100 g)$^{-1}$.

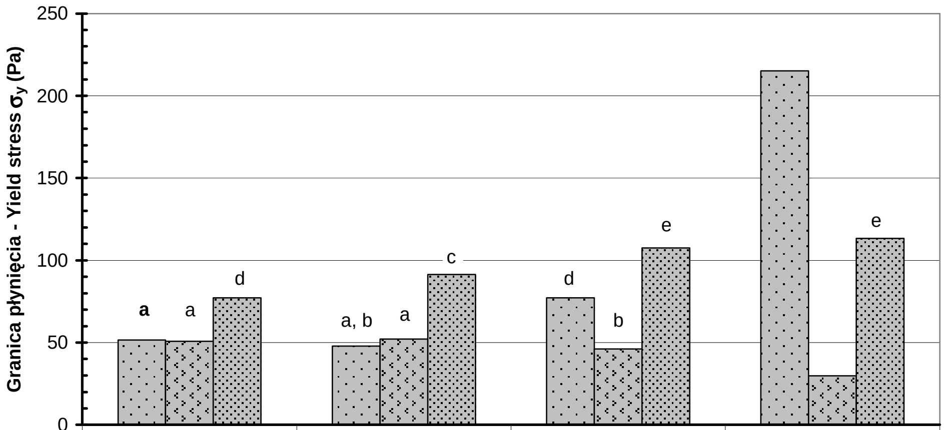
Table 1. Ingredients and overall chemical composition of the liver paté samples tested

Sample	Water content g (100 g)$^{-1}$	Fat content g (100 g)$^{-1}$	Ingredients*)
A	66.4	10.7	Chicken meat, giblets, semolina, soy protein, salt, milk powder, E621, E635, E250
B	69.7	15.7	Poultry meat, poultry liver, wheat flour, vegetable fat and protein, spices, E472c
C	65.0	20.6	Poultry meat, giblets, fat, starch, emulsifier, porcine skin, vegetable protein, spices, salt, E250

*) according to the manufacturer.

Yield stress

The rheological properties of the products analysed reflected differences in the composition of individual samples. Changes in mean values of the static yield stress σ_y in the samples examined as affected by various temperatures of measurements are illustrated in Figure 3. The data demonstrate that at temperatures of 10 and 15^{o}C, the samples of liver paté of series A and B were not significantly different. In turn, samples of the series C were characterized by a greater yield stress, hence, they should be considered as of worse spreadability. The variability in the yield stress value seems to be connected with water and fat content in the samples, but no detailed chemical composition analysis was performed in this study. Based on the yield stress σ_y values obtained, the samples tested might be classified as belonging to easy-to-spread category of foods, according to the spreadability map given by Daubert *et al.* (1998).



	10 °C	15 °C	20 °C	50 °C
A	51.6	47.8	77.3	215.2
B	50.9	52.1	46.2	29.9
C	77.3	91.3	107.5	113.3

Temperatura - Temperature (°C)

Fig. 3. Static yield stress of the liver paté samples tested – mean values denoted with the same letter do not differ significantly (p = 0.05)

The effect of temperature on the static yield stress was not explicit. In the case of homogenous substances, the yield stress decreases along with an increase in temperature (Steffe 1996). In the experiment reported here, along with a rise in temperature, the consistence of samples of B series at 20 and 50°C became more spreadable than at 10 and 15°C, whereas the other samples were characterized by an increase in the value of σ_y. It is likely to be the result of phase transitions occurring in components of liver paté tested, yet elucidation of the cause of such relationships requires further study.

Flow properties

Flow curves of the liver paté samples were plotted assuming that the equilibrium values of torque, settling at a given frequency of impeller rotation, correspond to values of shear stress σ developed on the surface of a product cylinder rotating in an immobile mass of the sample. In order to compute σ values, equation (1) with M_{eq} values substituted for M_{max} was used. The mean value of shear rate $\dot{\gamma}$ was calculated as a magnitude proportional to rotational speed of the impeller N

$$\dot{\gamma} = k' \cdot N \tag{2}$$

taking a factor of proportionality k' = 37.5 based on a previous study (Zander *et al*. 2006a). The analysis of the results demonstrated that the investigated samples of liver paté subjected to shearing behaved as a visco-plastic body, hence, a satisfactory approximation of the flow curves of $\sigma(\dot{\gamma})$ obtained with the vane impeller may be following linear equation for the flow curve of Bingham plastic, valid at the shear rate greater than 10 s^{-1}:

$$\sigma = \sigma_0 + \eta_p \dot{\gamma} \tag{3}$$

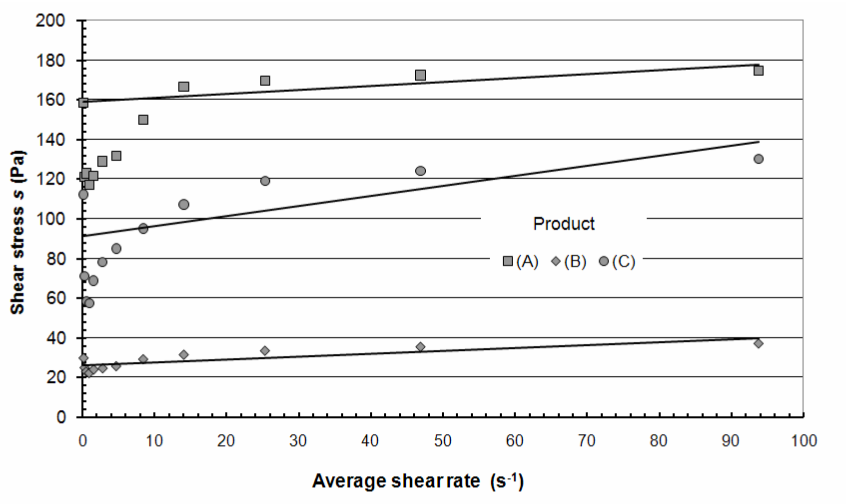


Fig. 4. Example of flow curves of the spreads tested (points) and approximation with the Bingham equation (continuous lines) at 10 °C – parameters of the equation are given in Table 2

Table 2. Parameters of Bingham equation (3) for flow curves of samples tested

Temperature (°C)	Sample tested					
	A		B		C	
	σ_0 (Pa)	η_p (Pa s)	σ_0 (Pa)	η_p (Pa s)	σ_0 (Pa)	η_p (Pa s)
10	27.91	0.25	46.36	0.19	84.08	0.55
15	41.46	0.24	49.56	0.10	54.02	0.38
20	40.64	0.20	36.24	0.12	70.69	0.31
50	159.0	0.20	26.04	0.15	91.46	0.51

Figure 4 illustrates an example of fitting the Bingham model to empirical data based on measurements conducted at a temperature of 10°C, whereas Table 2 displays all numerical values of the yield stress σ_0 and plastic viscosity η_p evaluated. The results obtained reflect the consistency diversity of the products examined and changes in their rheological properties with temperature in a similar range as the static yield stress σ_y discussed above (Fig. 3).

Almost all experiments demonstrated that after disruption of the primary structure of the sample resulting from exceeding the static yield stress at initially low shearing rates, a decrease occurred in values of shearing stress along with an increasing rotational speed of the impeller. Such an apparently abnormal course of the flow curves should be attributed to the potential formation of a thin layer of the examined material subjected to shearing between the motionless mass of a sample in a vessel and the rotating cylinder of the material entrapped between the impeller vanes. It is impossible to determine the thickness of this layer; hence, some authors claim that the flow curves obtained by means of a vane impeller do not provide absolute values of viscosity (Glenn *et al*. 2000). Nonetheless, it seems that data achieved with the use of the technique discussed may be applied for comparative purposes, e.g. in the assessment of food products quality, especially in cases when the use of narrow-gap rheometric sensors is not justified.

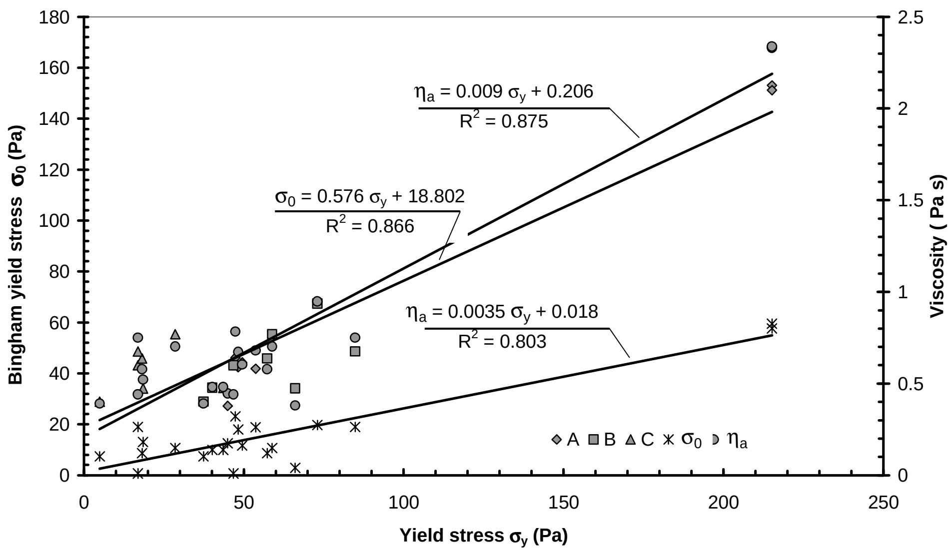


Fig. 5. Correlations between the rheological properties of samples tested and static yield stress (σ_y): σ_0 – Bingham yield stress, η_p – plastic viscosity, η_a – apparent viscosity

Detailed analysis of the rheological parameters of the spreads tested indicated that Bingham yield stress σ_0, as well as plastic viscosity η_p and apparent viscosity defined as $\eta_a = \sigma / \dot{\gamma}$ were correlated with the static yield stress σ_y, as shown in Figure 5. This may suggest that despite the complex rheological nature of this kind of food product the relatively simple, single-point measurement of static yield stress σ_y may deliver profound information about its consistence. This statement is in good agreement with assumptions of Daubert *et al*. (1998).

CONCLUSIONS

1. The characteristics of the rheological properties of liver paté samples obtained in the study demonstrated the possibility of applying the vane impeller for the evaluation of their consistency.
2. The result of single-point measurement of yield stress is an objective value and may be applied for the current monitoring of the quality of similar types of food products.

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ZASTOSOWANIE MIESZADŁA SKRZYDEŁKOWEGO DO OCENY REOLOGICZNYCH CECH PASZTETÓW DROBIOWYCH

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S t r e s z c z e n i e. Badano cechy reologiczne handlowych pasztetów wykorzystując mieszadło skrzydełkowe (d_v = 20,5 mm, h_v = 41,6 mm) i napęd reometru rotacyjnego Rheotest RV2. Pomiar naprężenia stycznego σ, występującego na ścianie bocznej cylindra materiału, formowanego przez obrót mieszadła z materiałem między łopatkami, pozwolił wyznaczyć statyczną granicę płynięcia σ_y badanych próbek oraz sporządzić krzywe płynięcia. Pomiary wykonano w temperaturach 15, 20 i 50°C. Badane pasztety charakteryzowały się zbliżoną do siebie zawartością wody mieszczącą się w granicach 65-69,7% i tłuszczu od 10,7 do 20,6%. Statyczna granica płynięcia próbek pasztetu σ_y wynosiła od 45 do 130 Pa i była zależna od temperatury. Krzywe płynięcia badanych próbek pasztetów wykazywały cechy płynu rozrzedzanego ścinaniem. Przebieg zmian naprężeń stycznych w funkcji częstości obrotów mieszadła odpowiadał charakterystyce tzw. idealnego smarowidła (ang. ideal, spread), czyli materiału posiadającego granicę płynięcia pozwalającą na utrzymanie kształtu próbki pod własnym ciężarem i jednocześnie stosunkowo małą lepkość pozorną. Liniowy przebieg zależności między naprężeniem stycznym a częstością obrotów mieszadła wskazywał na możliwość stosowania modelu Binghama do odwzorowania płynięcia próbek pasztetów przy szybkościach ścinania powyżej 10 s^{-1}. Doświadczenia wykazały duże zróżnicowanie lepkości plastycznej próbek pochodzących od różnych producentów.

S ł o w a k l u c z o w e: granica płynięcia, lepkość plastyczna, mieszadło skrzydełkowe, pasztet