Flow Properties of Common Norwegian Dairy Products

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ABSTRACT

Flow properties of a selection of common Norwegian dairy products were tested by a rheological rotational method, changing the shear rate up and down between 0.01 and 200 s^{-1}. Herschel-Bulkley model fitted well to the downward curve. Samples proved to be plastic as indicated by high yield stress values. A marked hysteresis loop was observed on flow curves indicating strong time-dependent behavior of all the samples tested.

INTRODUCTION

Fermented dairy products have three main categories: cheese, yoghurt and fermented liquid milk .Today some of them have even probiotic effects.

A required step in cheesemaking is separating the milk into solid curds and liquid whey. Usually this is done by acidifying (souring) the milk and adding rennet. The acidification can be accomplished directly by the addition of an acid like vinegar in a few cases (paneer, queso fresco), but usually starter bacteria are employed instead. These starter bacteria convert milk sugars into lactic acid. The same bacteria (and the enzymes they produce) also play a large role in the eventual flavor of aged cheeses. Most cheeses are made with starter bacteria from the *Lactococci, Lactobacilli*, or *Streptococci* families. Swiss starter cultures also include *Propionibacterium shermanii*, which produces carbon dioxide gas bubbles during aging, giving Swiss cheese or Emmental its holes. After curd formation the whey is removed. In Norway the whey is utilized as "whey cheese" or mysost [1, 2].

Yoghurt can be considered as a curdled milk product, made of pasteurized milk, by adding starter culture (*Streptococcus thermophilus*) and other ingredients if needed (flavor, sweetener, colorant, stabilizer, gum). Then the milk is incubated at 40°C for 3 hours, cooled down to 15-20°C, and added live culture. Other forms of yoghurt as frozen or stirred yoghurt and yoghurt drinks are also available and popular products. Fat content, solids-not-fat, flavors and appearance are widely varied in different countries [3,4].

Sour milk products are the most basic fermented liquid milk products. Many variants are made of low fat milk, which is pasteurized and added starter culture (*Bifidobacterium bifidum, Lactobacillus acidophilus, Bifidobacterium lactiscultur, Lactobacillus rhamnosus GG etc.*). Then the nilk is fermented to pH 4.65-4.55, and cooled to 4-6°C. Sour milk products may not contain any stabilizer or gum and are considered a health food due to live cultures[3, 5].

Kefir is a fermented liquid milk product characterized by small amounts of alcohol. It contains its inoculant, the kefir grains. The processing technology consists of two main parts: preparation of mother kefir and preparation of drinkable kefir. For the first part pasteurized milk is added to the kefir grains. After 24 hours floating grains are filtered out from the fermented milk. They are then saved for next fermentation, while fermented milk is mixed with fresh, pasteurized milk and fermented for 1-3 days, then cooled, stored and distributed[3].

Mysost ("whey cheese") is a typical Norwegian dairy product. It is made by concentration of whey by long-time heat treatment, without any fermentation or incubation. Whey proteins are coagulated and a high concentration of lactose is developed. It is more or less a caramel.

Dairy products have complex colloidal structure and show marked non-Newtonian rheological behaviors, most of them are plastic (kefir, sour milk products), or strongly thixotropic [6,7].

The aim of present study was to investigate the flow properties of common Norwegian dairy products by rotational rheological techniques.

MATERIALS AND METHODS

Rheological characterization of four different store bought cream cheeses and whey cheeses were investigated; (Philadelphia light: 1PhL, prim letago: 2PL, prim original: 3PO, prim lett: 4PLe) and five different sour milk products (kefir: 5Kef, yoghurt 6Yh, yoghurt drink: 7YD, cultured milk: 8Cu, skim milk: 9TM).

For rotational measurements a Physica UDS 200 (Paar Physica, Physica Messtechnik GmBH, Germany) rheometer was used. A cone and plate measurement system (MK 24 cone, 75 mm in diameter, $\alpha = 1°$ and TEK 180 plate measuring cell) with a 0.05 mm central measuring gap was used. Rotational measurements were carried out in controlled shear rate mode at 4°C. The shear rate increased logarithmic from 0.01 to 200 s^{-1} (interval 1), and then decreased from 200 s^{-1} to 0.01 s^{-1} (interval 2). Five replicates per sample were measured.

Based on the flow curve (Fig. 1) six different parameters were determined: at interval 1 a local maximum (M) was observed on the curve. The shear rate ($\dot{\gamma}_M$, s^{-1}) and the corresponding shear stress (τ_M, Pa), are both characteristic for the material tested. At interval 2 the Herschel-Bulkley model was fitted to the measured curve. Main parameters of the model: yield stress (τ_0, Pa), consistency (C, Pa.s) and power law index (n) were determined, and also the correlation coefficient (R^2). Thixotropic behaviour of the samples was investigated by hysteresis loop area (A, $Pa.s^{-1}$).

RESULTS AND DISCUSSION

Sample with shear stress higher than 10^4 Pa was not measurable by the method described. A typical flow curve of dairy products tested is shown in Fig. 1.

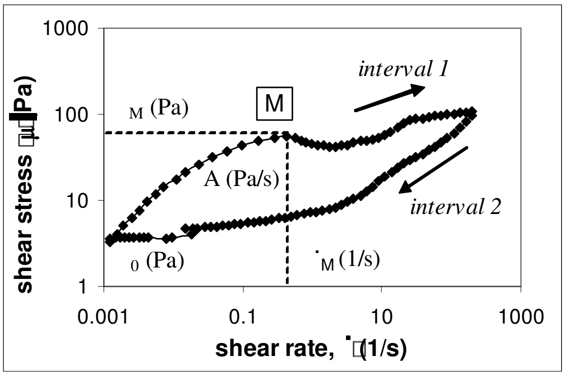

Figure 1.
Main parameters of the flow curve of dairy products.

Table 1 shows the main parameters from Herschel-Bulkley model (Eq. 1) fitted to the downward curve (interval 2).

$$\tau = \tau_0 + C \cdot \dot{\gamma}^n \quad (1)$$

(τ: shear stress [Pa], τ_0: yield stress [Pa], C: consistency [Pa.s], $\dot{\gamma}$: shear rate [s^{-1}], n: power law index, R^2: correlation coefficient)

Table 1. Parameters with standard deviation from Herschel-Bulkley model fitted to interval 2 of the flow curve of dairy products.

Product	τ_0	C	n	R^2
1Phl	100.7 ±8.62	64.3 ±0.32	0.46 ±0.03	0.997
2PL	32.1 ±10.05	202.7 ±19.5	0.63 ±0.04	0.969
3PO	25.0 ±2.94	106.0 ±13.1	0.59 ±0.04	0.940
4Ple	13.4 ±1.52	131.5 ±17.3	0.55 ±0.03	0.972
5Kef	1.6 ±0.04	2.7 ±0.07	0.46 ±0.004	0.998
6Yh	4.1 ±0.34	2.8 ±0.24	0.61 ±0.04	0.996
7YD	0.002 ±0.001	0.2 ±0.02	0.74 ±0.02	0.985
8Cu	1.5 ±0.13	2.3 ±0.11	0.47 ±0.01	0.997
9TM	1.1 ±0.09	2.2 ±0.15	0.43 ±0.004	0.999

The Herschel-Bulkley model proved to be adequate for all of the samples tested as indicated by the high value of correlation coefficient $0.940 < R^2 < 0.999$.

All of the dairy products investigated showed marked shear-thinning behavior as indicated by the low values of power law index ($0.46<n<0.74$). Skim milk (9TM) had the strongest pseudoplastic property (the lowest n value: 0.43). This product has no gelatinizing component. The texture is developed by the colloidial structure of milk and the bacterial culture used, producing a structure which can be easily destroyed by shearing. Power law index was 0.46-0.47 for cheese cream (1Phl), kefir (5Kef), and cultured milk (8Cu), indicating that these products showing Casson type rheological behavior, and higher resistancy for shearing. Whey cheese creams and yoghurt (6Yh) proved to have stronger structure as indicated by the n value of 0.61. Yoghurt drink (7YD) showed the highest n value (0.74), which can be explained by the lack of a real gel structure, producing similar flow behavior as milk, which is a Newtonian liquid.

All of the dairy products investigated proved to be plastic, as indicated by the yield stress values higher than zero, except for yoghurt drink. Kefir, skim milk and cultured milk have low yield stress values (1.1-1.6 Pa) as these products can be easily poured from the bottle. Yoghurt drink has thicker consistency but can be poured as well. Whey cheese creams had yield stress in higher order of magnitude (13.4-32.1 Pa) and cheese cream had the highest (100.7 Pa). These products are solid in the box during storage, but could be spread when used.

The consistency index (K) was in different order of magnitudes for different types of dairy products: the highest K value was observed for whey cheese creams in range of 10^2Pa.s, for cheese cream was in range of 10^1 Pa.s. Sour milk products (kefir, yoghurt, and skimmed milk products) were in range of 10^0 Pa.s and the lowest was for the yoghurt drink (0.2 Pa.s).

The consistency (or apparent viscosity) refers to the thickness of the products and can be correlated to the perceived texture which is an important factor for consumers[8]. Whey cheese creams proved to have a special texture as they have very high consistency values compared to cheese creams. This phenomenon can be due to the high carbohydrate (lactose) content of these products (54%) developed by long term heat treatment. Yoghurt drink was parted from other sour milk products having very low consistency value due to the homogenisation after fermentation[3].

Time dependent behavior of dairy products was also tested in this experiment. Hysteresis loop area and parameters of local maximum observed on flow curve of dairy products are shown in Table 2.

Table 2. Hysteresis loop area and parameters of local maximum observed on the interval 1 of the flow curve of dairy products (with standard deviation).
A: hysteresis loop area [Pas^{-1}], τ_M: shear stress at local maximum [Pa], $\dot{\gamma}_M$ shear rate at local maximum [s^{-1}].

Product	A	τ_M	$\dot{\gamma}_M$
1Phl	67 674	1 759	0.6
	±3722	±450	±0.1
2PL	227 514	4 610	43.3
	±54180	±23	±3.2
3PO	424 431	4 623	90.5
	±65118	±67	±11.6
4Ple	434 931	4 454	96.3
	±53036	±249	±9.0
5Kef	870	9.4	0.1
	±53	±1.0	±0.02
6Yh	7 538	55.2	0.4
	±602	±9.9	±0.05
7YD	25	0.1	0.2
	±0.5	±0.1	±0.001
8Cu	376	5.9	0.1
	±13	±0.9	±0.02
9TM	291	3.6	0.1
	±15	±0.4	±0.02

Hysteresis loop area (A, Pas^{-1}) is an index of the energy needed to destroy the structure responsible for flow time dependence (thixothropy)[9]. The higher A value is observed, the higher energy is needed to break the structure of material tested.

Whey cheese creams have thixothropy (in range 10^6 Pa/s), maximum shear stress ($4*10^4$ Pa), and shear rate at maximum (90, 40 s^{-1}) in a higher order of magnitude than cheese cream. However, there is a difference between types of whey cheese: Prim letago proved to be easier to gulp or spread on bread as indicated by the lower thixothropy, lower consistency, and lower shear rate at maximum than Prim original and Prim lett. Cheese cream has similar shear rate at local maximum as the sour milk products, as it is very easy to gulp or spread.

Among sour milk products yoghurt (6Yh) showed the highest A value, indicating its' marked thixothropy derived from the gel structure developed during fermentation. Gel-like structure can be perceived during consumption as indicated by the high τ_M vales.

Kefir and skimmed milk products (8CU, 9TM) showed similar amount of thixothropy and the same shear rate at maximum. However, thicker perceived texture of kefir is indicated by its higher shear stress at maximum. Yoghurt drink proved to be similar to milk, as it showed very low A and local maximum values.

CONCLUSION

Objective rotational rheological measurements provided extensive qualification of flow properties of dairy products with high degree of reproducibility.

ACKNOWLEDGMENTS

The authors gratefully acknowledge Rezessy Szabó Judit, Balla Csaba and Barta József (Corvinus University of Budapest) and Trude Wicklung (IBKM, Norwegian University of Life Sciences) organizing the study trip to Norway with kind help of Tempus Közalapítvány (07/002/NA/N-134) and Olga Lothe for technical assistance.

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