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To study rheological modeling of time independent flow behaviour of *Lassi*

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Abstract
The rheological characteristics of *Lassi* were studied by using a computer-controlled rotational viscometer over a range of total solids (TS) sugar contents and stabilizers such as carrageenan, pectin and locust bean gum (LBG). The viscometric data were converted into the basic shear stress vs. shear rate form using Mitschka method. From the shear rate-shear stress data, the flow nature of *Lassi* was evaluated. The apparent viscosities of the systems decreased with increasing shear rate, indicating pseudoplastic behaviour with yield stress. The rheological behaviour of *Lassi* was adequately described by the Herschel-Bulkley and Casson models with a high coefficient of determination (R 2) and low root mean square error (RMSE). The Ostwald De Waele model did not fit very well because of the yield stress in *Lassi*. The Herschel-Bulkley yield stress (σ 0), consistency coefficient (K) and the flow behavior index (n) were determined. The values of σ 0, 'K' and 'n' ranged from 0.638-7.725 Pa, 0.330-0.834 Pa.s n and 0.514-0.701, respectively. The main and interaction effects of these selected factors on the apparent viscosity, yield stress, consistency coefficient and flow behaviour index were found to be highly significant.

Keywords: Rheological Modeling, Viscometric Analysis, *Lassi*, Indian Drinking Yoghurt

Introduction
Fermented milk products are popular because of their therapeutic and nutritional qualities. *Lassi* and *Dahi* are the important fermented milk products of India. *Lassi* is the viscous liquid obtained after churning of *Dahi* and adding sugar into it. It has a characteristically sweet and sour taste. The key quality attributes of *Lassi*, considered essential by consumers, are its rheological properties commonly referred to as body and texture or consistency. The flow properties, such as viscosity, yield stress, thickness, pourability, spreadability, and firmness contribute substantially to facilitate pumping and commercial processing, as well as, to promote consumer acceptance. Hence, the rheological characterization of *Lassi* is very important, particularly in relation to structure and stability, and processing conditions.

The knowledge of rheological properties is of importance in processing, handling, process design, product development and quality control. Viscometric data are also essential for the design evaluation of food processing equipment such as pumps, piping, heat exchangers, evaporators, filters and mixtures. In general, fermented milks rarely obey Newton's law of viscosity. They exhibit variety of non- Newtonian effects, such as shear thinning, yield stress, viscoelasticity and time- dependency. Flow behaviour models such as Ostwald de Waele (power law), Herschel- Bulkley, Casson's and Cross equation are reported in literature to describe the non-Newtonian behaviour of food products.

Materials and methods
The raw materials like fresh raw milk and LF-40 *Dahi* culture required for the study were obtained from the experimental dairy plant and dairy bacteriology section of the Southern Regional Station of NDRI, respectively. Crystalline sugar for sweetening the *Lassi* was obtained from the market (Star Bazaar, Bangalore).

Preparation of *Lassi*
Fresh raw milk was standardized to 3.0% fat and 8.5% SNF, and homogenized in a triple-action homogenizer (Model APV, Crepaco, Chicago, IL). The operating pressures in the first and second stages of the homogenizer were set to 13.79 and 3.45 MPa, respectively. The homogenized milk was subjected to heat treatment at 85°C for 10 min by indirect heating,

and subsequently cooled to 30°C. This time-temperature combination of heat treatment was selected based on earlier studies (Bienvenue *et al.* 2003) [1]. Exactly 1.5% (w/w) of LF-40 culture was then added to 500 mL samples of milk, taken in 600 mL volume glass beakers. Carrageenan, locust bean gum and pectin (Hi-Media Laboratories Pvt. Ltd, Mumbai) were tested independently as stabilizers to improve the viscosity and consistency of *Lassi*. These stabilizers, at concentrations of 0.05, 0.1 and 0.15% (w/v of milk), were added to cooled milk at 30°C. The required quantity of stabilizers were weighed to 0.1 mg accuracy in an electronic precision balance (Model CP 323S, Sartorius Mechatronics, India) and dissolved in a small quantity of heated milk before incorporation into 500 mL of milk in the beakers. The cultured milk was incubated at 30°C for 20 h to make *Dahi*/curd. Theincubation temperature was closely related to the type of strains used. The incubator had digital temperature control with 0.1°C accuracy (Deen Instruments, Bangalore), and was fitted with a recirculation fan for uniform distribution of temperature inside the cabinet. After incubation, sugar at concentrations of 10, 15 and 20% (w/v) was added to the curd. Similarly, water, at calculated quantities, was added to the curd to achieve the desired total solids (TS) concentrations of 11.50, 10.35 and 9.20%. The water addition corresponds to 0, 10 and 20% on weight basis of curd. The curd-sugar mixture was then gently stirred 30 times using a hand-operated stainless steel vertical stirrer to blend the water and dissolve the added sugar. The flow diagram for the production of *Lassi* is presented below.

Raw milk
↓
Standardization (3% fat, 8.5% SNF)
↓
Two-stage homogenization (13.79 and 3.45 MPa)
↓
Heat treatment (indirect heating at 85°C for10 min)
↓
Cooling to 30°C
↓
Addition of LF-40 culture (1.5% w/v of milk)
↓
Addition of stabilizer (0.05, 0.10 and 0.15% concentrations)
↓
Incubation at 30 ° C for 20 h
↓
Addition of sugar (10, 15 and 20% w/w)
↓
Dilution with water (9.20, 10.35 and 11.50% TS)
↓
Stirring with vertical hand stirrer (30 times)
↓
Lassi

Experimental Design and Statistical Analyses

The effects of all four factors namely sugar content (0, 10 and 20%), total solids content (9.20, 10.35 and 11.50%), stabilizer type (carrageenan, locust bean gum and pectin) and stabilizer concentration (0, 0.05, 0.1 and 0.15%) were studied using a factorial experimental design, which resulted in 81 formulations (3 x 3 x 3 x 4 levels). Each formulation was made 3 times and tested in the viscometer. The data on apparent viscosity and Herschel-Bulkley model parameters were analyzed using the 'Proc Mixed' procedure of SAS (V. 9.1, SAS Institute Inc., Cary, NC), with the significance level of $\alpha \leq 0.05$. The differences between the treatment means were compared using 'lsmeans' statement. The viscometric results obtained from this study were fitted to different models using Microsoft Excel 2003 software. The root mean squared error (RMSE) index was used to decide the model that provided the best fit of the experimental data.

Table 1: Ranges of flow behaviour index, shear stress and shear rate for *Lassi* samples

Sample	Flow behavior index, 'n'	Shear stress, Pa	Shear rate, s-1
Carrageenan			
10% Sugar	0.234-0.272	8.350-17.020	7.226-85.477
15% Sugar	0.276-0.326	3.540-12.030	6.232-72.099
20% Sugar	0.267-0.333	3.170-11.820	6.146-61.459
Pectin			
10% Sugar	0.245-0.319	3.610-14.890	6.371-77.879
15% Sugar	0.321-0.373	3.169-13.720	5.699-63.370
20% Sugar	0.315-0.386	2.451-10.629	5.398-63.952
LBG			
10% Sugar	0.310-0.508	1.610-14.970	4.456-64.374
15% Sugar	0.337-0.543	1.880-11.641	4.271-63.370
20% Sugar	0.346-0.575	1.862-10.413	4.730-59.762

From Table 1, it could be inferred that the flow behaviour index of *Lassi* containing carrageenan was lowest while that of LBG-added *Lassi* was highest. A lower value of 'n' was indicative of a stronger departure from Newtonian behaviour. Consequently, the shear stresses and shear rates were highest in samples containing carrageenan as stabilizer. On the other hand, the flow behaviour index exceeded 0.5 in LBG samples, suggesting that those samples (though not all) were closer to exhibiting Newtonian behaviour when compared to those stabilized with carrageenan. The flow behaviour index increased rather linearly with increasing sugar content. Irrespective of the type of stabilizer, addition of sugar in *Lassi* had a negative influence on the shear stress and shear rate values.

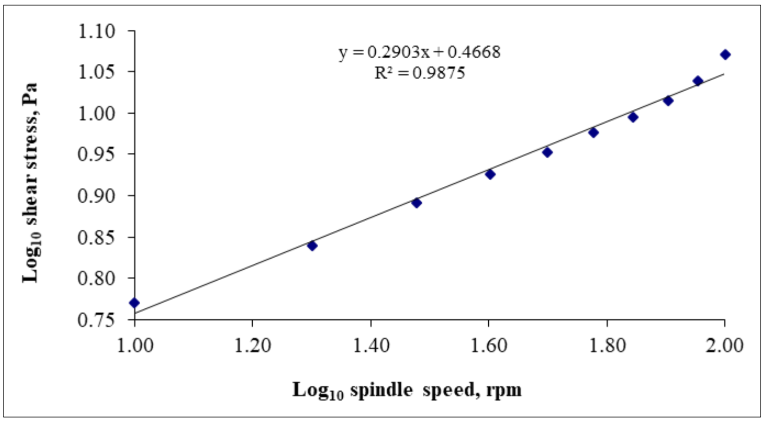

Fig 1: Plot of $\log_{10}$ shear stress (Pa) vs. $\log_{10}$ spindle speed (rpm) for computation of flow behaviour index and shear rate under Mitschka method.

Flow Behaviour Curves of *Lassi*

Shear Stress vs. Shear Rate Curves

The *Lassi* samples produced in this experiment exhibited pseudo-plastic behavior (shear thinning). This non-Newtonian flow was expected, as was commonly found in yoghurts and related products (Keogh and O'Kennedy 1998) [7]. The reason for shear thinning flow behaviour was that an increased shear rate deforms and/or rearranges particles, resulting in lower flow resistance and consequently lower viscosity. Morris *et al.* (1981) [8] explained that shear thinning was observed when the rate of shear exceeded the rate at which new entanglements could be formed. The authors also added that the depletion in the concentration of non-specific crosslinks led to the observed reduction in viscosity at high shear rates.

The flow behaviour index (n) and consistency coefficient (K) were calculated from the slope and intercept, respectively of the linear regression plot as discussed in section 3.4. The flow behaviour index of *Lassi*, at all TS and sugar contents, was less than 0.62. The effects of yield stresses on flow behaviour curves were evident at low shear rates (Fig. 3) because the flow behaviour at low shear rates was strongly influenced by yield phenomena and wall effects.

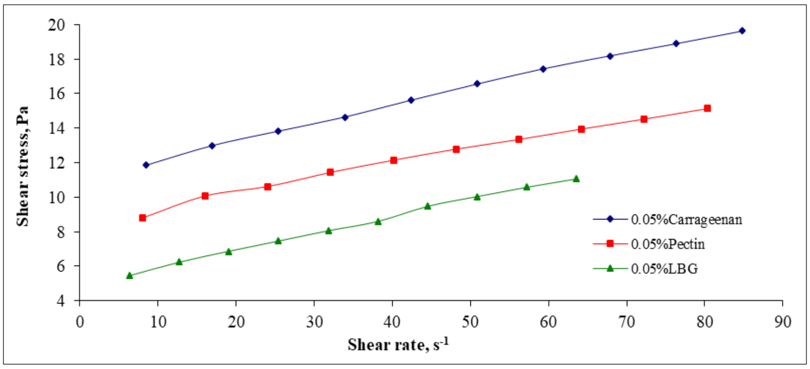

Fig 2: Flow behaviour curves of *Lassi* containing 10% sugar and 11.50% TS and different stabilizers

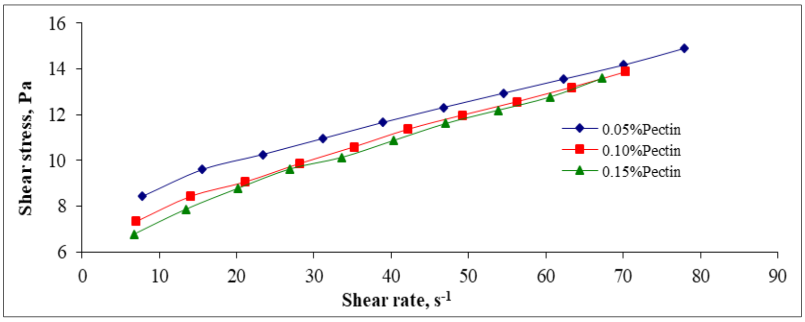

Fig 3: Flow behaviour curves of *Lassi* containing 10% sugar and 11.50% TS and stabilized with pectin at different concentrations

Visual observation of the *Lassi* also showed that the samples made with LBG were very different than those made with carrageenan or pectin. While the *Lassi* made with both carrageenan and pectin were thicker, whiter and more homogeneous, the LBG samples were thin, slight yellowish, had large amounts of aggregated protein and displayed whey separation, particularly at 0.10 and 0.15% concentrations. Therefore, the consistency of the LBG samples was very poor. Hence, *Lassi* stabilized with LBG was completely unacceptable as a drink. On the contrary, none of the carrageenan and pectin added samples exhibited any whey separation, and their body and texture were intact.
The lack of whey separation in *Lassi* made with carrageenan and pectin indicated that there was sufficient amount of negatively-charged particles in the hydrocolloid to provide repulsion on the positively-charged protein molecules of the *Lassi*, thereby stabilizing the matrix. It was presumed that LBG formed complexed with the milk proteins that precipitated out of solution. Shukla and Jain (1991) reported that pectin was useful as a stabilizer to prevent whey separation in yoghurt made from buffalo milk.

Apparent Viscosity–Shear Rate Model

Another form of studying the non-Newtonian behaviour of *Lassi* would be to represent the apparent viscosity against the shear rate, and analyze its behaviour. As an example, the apparent viscosity as a function of shear rate at different concentrations of TS in *Lassi* stabilized with 0.15% pectin is shown in sample Fig. 4. During shearing, the apparent viscosity decreased to more or less a constant value, which was true for all samples. Thus, all the apparent viscosity vs. shear rate curves showed a strong shear-thinning behaviour (pseudoplastic). The reduction in viscosity of *Lassi* with increasing shear rate was related to the increasing alignment of constituent molecules to the rotational movement.

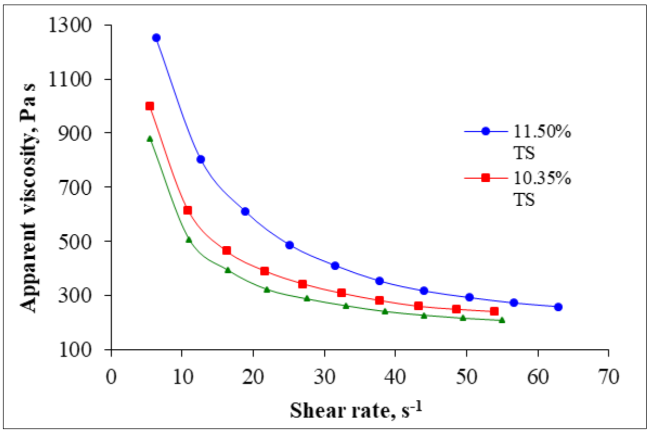

Fig 4: Apparent viscosity vs. shear rate curve of *Lassi* containing 20% sugar and stabilized with 0.15% pectin

Conclusion

The rheological characteristics of *Lassi* were studied by using a computer-controlled Brookfield RVDV II Pro rotational viscometer over a range of total solids (TS), sugar and concentrations of various stabilizers. The stabilizers evaluated were carrageenan, pectin and locust bean gum (LBG). The viscometric data were converted into the basic shear stress vs. shear rate form using Mitschka method. From the shear rate-shear stress data, the flow nature of *Lassi* was evaluated. The apparent viscosities of *Lassi* decreased with increasing shear rate, indicating pseudoplastic behaviour with yield stress.

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