Apparent Viscosity of Milk and Cultured Yogurt Thermally Treated by UHT and Vat Systems

A. E. LABROPOULOS, A. LOPEZ* and J. K. PALMER

Department of Food Science and Technology, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061

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ABSTRACT

Apparent viscosity of ultra-high-temperature (UHT) treated milk and of yogurt prepared from this milk was studied and compared to that of vat-treated milk and yogurt. UHT-treated milks (149 C, 3.3 sec) had an apparent viscosity of 2.3 to 2.7 cp, while the apparent viscosity of vat-treated milks (63 C and 82 C, 30 min) ranged from 1.9 to 2.0 cp. The apparent viscosity of unheated (raw) milk was 1.7 cp. The apparent viscosity of yogurt prepared from UHT-treated milk became nearly constant at 0.8 cp after 14 min of shearing, while the apparent viscosity of yogurts prepared from vat-treated milks ranged from 1.8 to 3.8 cp under the same conditions. All yogurts exhibited thixotropic behavior.

The physical character of the curd is of primary importance with reference to the consistency of cultured yogurts. Consistency or viscosity is defined as the resistance that a liquid offers to an applied shearing force (8). McKennel (10) discussed the limitations for measuring viscosities of non-Newtonian fluids with the falling sphere and the capillary tube. Dinsdale and Moore (3) noted advantages concerning the coaxial cylinder viscometer for rheological studies of non-Newtonian fluids.

Lundstedt (9) and Nielsen (11) indicated that all aspects of the process - heat treatment, incubation, and cooling - are important for improving the apparent viscosity of cultured yogurt products. Hrabova and Hylmar (6) noted that prolonged pasteurization at 85 C (185 F) increased the apparent viscosity of subsequently produced yogurt. Cooper et al. (1) observed that grainy texture in yogurt was related to slow acid development and low incubation temperature. Nielsen (12) reported that satisfactory yogurt texture was achieved by precooling to 25-29 C (77-85 F) in a plate heat exchanger followed by undisturbed cooling to 4 C (40 F). Galesloot and Hassing (5) claimed that viscous extracellular material production by the culture bacteria plays an important role in achieving satisfactory firmness and apparent viscosity of yogurt.

The present study compares the viscosities of UHT- and vat-heat treated whole bovine milks and of yogurts prepared from these milks. It is part of a broader study comparing the properties of yogurts prepared from either vat-treated or UHT-treated milk.

EXPERIMENTAL

Materials

Raw milk was obtained from the Virginia Polytechnic Institute and State University dairy farm in Blacksburg, Virginia. Powdered cultures of *Lactobacillus bulgaricus* and *Streptococcus thermophilus* were obtained from Chr. Hansen's Laboratory, Inc., Milwaukee, Wisconsin. These were then combined with sterilized milk to produce the starter culture inoculum.

Samples of raw milk were homogenized and heat-treated as follows: (a) in a continuous, indirect, helically-coiled tube UHT system at 149 C (300 F) for 2.2 and 3.3 sec holding process time, and (b) in a vat system at 63 C (145 F) and 82 C (180 F) for 30 min each. The samples were then cooled to 42 C (110 F) and inoculated with 3% starter culture *L. bulgaricus*: *S. thermophilus* = 1:1 ratio by wt. The inoculated samples were then incubated at 42 C (110 F) for approximately 4.5 h and stored at 4 C (40 F) for 12 to 48 h before viscosity determinations were made. Titratable acidity of yogurts was 0.93 ± 0.02% as lactic acid. Whole milk processed as mentioned above was also subjected to viscosity determinations within 12 to 48 h.

Procedures

A Haake Rotovisco, Model RV-3 viscometer (Haake Inc., Saddle Brook, NJ) was used to determine the apparent viscosity of the heat-treated milk and cultured yogurt samples. The Haake NV sensor system was applied to milk, and the MV II sensor system to the yogurt. A temperature of approximately 4 C (40 F) was maintained in the samples by circulating ice water from a constant temperature ice-water bath through a jacket of the assembly. The instrument was calibrated by the method prescribed in the Haake Rotovisco Operating Manual 105. Calibration was further checked by use of a Brookfield standard liquid with a viscosity of 9.6 ps.

The scale readings at various speeds were recorded for each of the milk and cultured yogurt samples; calculations of shear stress, shear rate and apparent viscosities were made in accordance with the procedures outlined in the Haake Manual 105. Thus, the shear stress, T, was represented as follows (Eq. 1):

\[ T = A \cdot S (\text{dyne/cm}^2) \] (1)
where "A" is the shear stress factor (given as 36 for the MV II sensor system, and 17 for the NV sensor system), and "S" is the scale reading.

The rate of shear, \( \gamma \), on the rotor surface was given by the following relationship (Eq. 2):

\[
\gamma = B/u \text{ (sec}^{-1}\text{)}
\]  

where "B" is the rate of shear factor (given as 529 for the MV II sensor system or 3140 for the NV sensor system); and "u" is the speed factor, which is a gear number, ranging from 1 to 162. Consequently, the value of apparent viscosity, \( \eta \), was derived by the formula (Eq. 3):

\[
\eta = \tau/\gamma \text{ (cp)}
\]  

RESULTS AND DISCUSSION

Yogurt apparent viscosity

Data on the effect of shearing time on yogurt apparent viscosity are shown in Fig. 1. An apparent viscosity determination for UHT-heat-treated yogurt for 2.2 sec is not shown in Fig. 1 because its viscosity was very close to that of the sample treated for 3.3 sec. Apparent viscosity values, as can be seen in Fig. 1, were drastically reduced in the first 4 min and then tended to stabilize. Figure 1 also clearly shows a generally expected trend of decrease in apparent viscosity with increase in time of shear, which is a thixotropic behavior. This could be explained by the occurrence of syneresis during the shearing of the yogurt samples, which indicates the disruption of a portion of the relatively rigid gel structure, hence a lower bonding density per unit volume.

![Figure 1. Effect of time of shearing on the apparent viscosity of representative UHT- and vat-made yogurts at 4.4 C (40 F). Haake MV II Rotovisco was applied with shear rate, \( \gamma = 29.4 \) sec\(^{-1}\).](image)

In practical terms, UHT yogurt has a thickness after shaking resembling that of buttermilk and offers a possible alternative to milk and milk-based drinks. Yogurt drinks are not new products in Europe, but are a new concept to many American consumers. Various new drinkable yogurt products could conceivably be prepared from UHT yogurt.

**Viscometric behavior of different heat-treated milks**

Since yogurt prepared by the different process systems had quite different rheological properties, it was of interest to compare the apparent viscosities of milks treated in the different process systems.

The shear stress or tangential force per unit area was plotted against shear rate on a semilog graph. The results obtained are shown in Fig. 2. The data indicate that UHT-milk is more viscous than vat-milk and vat-milk more viscous than raw milk, which approaches the Newtonian behavior of water. The shear stress and the shear rate increased as the temperature increased in the vat system, and as the holding residence time increased in the UHT process.

![Figure 2. Semi-logarithmic shear rate: shear stress relationship of UHT and vat processed milk samples applying the Haake Rotovisco (NV sensor) viscometer.](image)

Figure 2 shows the apparent viscosities of various heat-treated milks as compared to unheated or raw milk and water at a constant rate of shear of 29.4 sec\(^{-1}\). Again, it can be seen that the UHT-heat-treated milk samples were more viscous than the conventional vat-treated milk. Increased residence holding times in both UHT- and vat-process systems induced increased apparent viscosities in milk. Thus the chemical and biochemical changes in milk induced by heat affect the apparent viscosity of the product.

Extensive studies have indicated that the apparent viscosity of milk is a complex property and its value falls within the range of 1.5 to 2.0 cp at 20 C (7). However, close agreement between investigators for apparent viscosity of milk has not been achieved. Among the factors influencing the apparent viscosity, heat treatment is very important. The tendency of milk to increase in apparent viscosity upon heating as it approaches the
point of coagulation of the proteins is very well known, as it is the basis for producing high viscosity in superheated condensed milk.

As Fig. 3 shows, milk had the highest viscosity after UHT-heat treatment. However, UHT-treated milk produces a cultured yogurt of considerably lower apparent viscosity. Presumably the rheological behavior of heat-treated milk is very complex, depending mainly on process temperature and time, and physical state of its disperse phase. Reports in the literature indicate that the physical state of fat and proteins is affected by various factors, such as the experimental conditions under which the observation is made, the thermal and mechanical treatments, pH and aging. Therefore, the type of heating system and time-temperature conditions affect considerably the body and texture of cultured products.

**SUMMARY AND CONCLUSIONS**

An evaluation of the effect of UHT- and vat-thermal process treatments on apparent viscosity properties of milk and cultured yogurt resulted in the following conclusions: (a) all heat-treated milk showed a slight deviation from the Newtonian behavior of water, with the UHT-treated milk having the highest deviation; (b) the apparent viscosity of cultured yogurt made by a vat process was higher and more shear-time dependent than the same product made by a UHT process; (c) the time dependency pattern indicated thixotropic characteristics for both UHT- and vat-processed cultured yogurts and (d) the results suggest that UHT-cultured yogurt could be of more value as a drinkable rather than as a spoonable product.

UHT-processed milk is a potential substrate for yogurt cultures in the manufacture of yogurt products of low relative viscosity. Further research is needed to determine the cause for variations in apparent viscosity of milk and cultured yogurts thermally processed by different systems. Some of the causes may be: (a) decrease in oxidation-reduction potential of heated milks, (b) destruction of heat-labile inhibitors, (c) partial hydrolysis of proteins and (d) denaturation of serum (whey) proteins.

**REFERENCES**