Correlation of Dynamic and Steady Flow Viscosities of Food Materials

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Abstract:
Eight commercial foods representing a wide range of viscosities (i.e. honey, condensed milk, mayonnaise, tomato ketchup, cream cheese, yogurt, process and *Mozzarella* cheeses) were investigated. Their steady shear viscosity and dynamic complex viscosity were determined by rheological measurements at two temperatures using a Bohlin-CVO rheometer. Based on experimental data, shear rate dependence of steady flow apparent viscosity and frequency dependence of dynamic viscosity was established and compared. It was determined that for condensed milk, tomato ketchup and mayonnaise, a modified Cox-Merz relation could be established. For cream cheese, a generalized Cox-Merz relation was proposed; and for yogurt, a deviation from the Cox-Merz rule was found. For *Mozzarella* and process cheeses a sharp drop in steady shear viscosity was noticed between 1~10 s^{-1} shear rate range. The Cox-Merz rule was not applicable for these cheese samples.

Zusammenfassung:
Acht kommerziell erhältliche Lebensmittel mit einem breiten Viskositätsbereich (Honig, Kondensmilch, Mayonnaise, Tomatenketchup, Rahmkäse, Joghurt, Schmelzkäse und Mozarellakäse) wurden rheologisch untersucht. Ihre stationäre Scherviskosität und komplexe Viskosität wurde bei zwei verschiedenen Temperaturen mit einem Bohlin-CVO Rheometer bestimmt. Anhand der experimentellen Daten wurde die Scherratenabhängigkeit der scheinbaren Viskosität in stationärer Strömung, sowie die Frequenzabhängigkeit der dynamischen Viskosität bestimmt und verglichen. Es kann gezeigt werden, dass für Kondensmilch, Tomatenketchup und Mayonnaise eine modifizierte Cox-Merz Regel verwendet werden kann. Für Rahmkäse kann eine verallgemeinerte Cox-Merz Regel vorgeschlagen werden, während für Joghurt eine Abweichung von der Cox-Merz Regel gefunden wird. Für Mozarella und Schmelzkäse stellt man ein starkes Abfallen der stationären Scherviskosität im Scherratenbereich 1~10 s^{-1} fest. Die Cox-Merz Regel kann auf diese Käseproben nicht angewandt werden.

Rèsumé:
Huit produits alimentaires commerciaux, représentant une vaste gamme de viscosités (i.e. miel, lait condensé, mayonnaise, tomato ketchup, crème de fromage, yahourt, fromages industriels et Mozzarella), ont été étudiés. Leur viscosité en cisaillement établi et leur viscosité dynamique complexe furent déterminées par des mesures rhéologiques menées à deux températures, en utilisant un rhéometre Bohlin-CVO. Basés sur les données expérimentales, la dépendance de la viscosité apparante en écoulement établi avec la vitesse de cisaillement et la dépendance fréquentielle de la viscosité dynamique ont été établies et comparées. Il est apparu que pour le lait condensé, le tomato ketchup et la mayonnaise, une relation de type Cox-Merz modifiée pouvait être établie. Pour la crème de fromage, une relation Cox-Merz généralisée a été proposée. Pour le yahourt, un écart par rapport a la loi Cox-Merz a été trouvé. Pour la Mozzarella et les fromages industriels, une chute abrupte de la viscosité en cisaillement établi fut reportée entre des vitesses de cisaillement allant de 1 a 10 s^{-1}. La loi de Cox-Merz ne fut pas applicable pour ces échantillons fromagers.

1 *INTRODUCTION*

Most foods exhibit time dependent properties of viscoelastic materials. Viscoelastic properties of fluid and semi-solid foods can be characterized by classical rheological experiments such as SAOS (small amplitude oscillatory shear), stress relaxation, shear stress growth and normal stress growth. Essentially, it should be possible to interrelate true material properties obtained from different experiments. This is useful because experimental limitation of one type of experiment (slippage, migration of sample, etc.) can be overcome by using a different experiment and then relating those material properties back to the framework of interest, and also as independent comparisons of results for validation.

Several investigations on rheological properties of polymer solutions have shown that there is a correlation between functions describing the dynamic properties and those characterizing the properties in steady shear flow. An important

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material property. As observed in associating polymer solutions, a sharp drop in steady shear viscosity may be attributed to the existence of clusters of associating polymers (microgel) that behave like soft particles in a low viscous dispersing medium once the associative network is destroyed [21]. At 55 and 60°C the cheeses are past their softening point and are in the melting state [22]. Therefore, the fat phase separates from the protein matrix. It is possible that when shear rate is beyond some critical value (between 1 to 10 s^{-1}), the protein network of the cheeses is broken, casein molecules form small clusters which disperse in melting fat. As we know, process cheese has low fat content which reduces the possibility of slipping, we also observed a sharp drop in steady shear viscosity. Of course, this explanation should be justified by other measurements to determine to what extent slippage has played a role in our data. However, we present the data as an interesting observation which may stimulate future research.

Therefore, for mayonnaise, condensed milk, tomato ketchup and *Mozzarella* cheese, which can be described by a modified Cox-Merz rule, there are large deviations from the original Cox-Merz rule. In Table 5 we list deviations from the original Cox-Merz rule for some polymers reported in the literature. Compared to many common polymers, food materials deviate a larger extent. Further research is needed to determine the exact reasons; we expect that the biphasic or even multi-phasic nature of most food materials may turn out to be the main concern. As shown in Table 5, filled polymer system (that is polymer matrix strengthened with solid particles, like wood fibers, charcoal particles or even tiny metal particles, etc.) has the largest deviation from the original Cox-Merz rule which is in the same range as some food materials. It has been proposed that this large deviation is due to the biphasic nature of the filled system [23-25].

5 CONCLUSION

The steady shear viscosity of many food materials and their corresponding linear viscoelastic properties are not simply related by the Cox-Merz rule. For some food materials, modified or generalized Cox-Merz rules can be established. Compared to some common polymers, the food materials deviate form Cox-Merz rule to a larger extent. Nonetheless, it may still be possible to estimate steady shear viscosity for many foods from their SAOS test data when shear rate is too high to be measured experimentally.

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[1] Mention of brand names is strictly for the sake of providing full and factual information about the product.

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