In-line, Real time Rheology of Bakery Shortening

We demonstrate, for the first time, that the rheology of bakery shortening can be measured in-line, in real time without the need for sampling and manual measurement.

In this report, we investigate the potential for automating and enhancing the quality control of bakery shortening during delivery to the facility. Currently, the only method in place for assessing the quality is through batch testing using cone penetrometry. A typical quality control workflow includes obtaining manual samples from the flow stream as the material is pumped to the silos for storage and making manual measurements using a cone penetrometer. An image of the delivery routine and the equipment used for quality control is shown in Figure 1 (a) and (b) respectively. However, these traditional manual techniques for controlling the properties of ingredients are becoming less reliable due to factors like diversified supplies, food safety concerns, hygiene standards, and a shortage of skilled labour.

We propose exploring the use of in-line rheology measurement with the OnLine Rheometer Series 1000 (OLR) to improve and automate this process. The aim is to address the increasing need for automation in the baking industry while maintaining control over the flow properties of critical ingredients. By implementing automated quality control measures, advantages such as increased production volumes, improved quality, and cost savings can be achieved.

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Figure 1

Figure 1. (a) Image shows the shortening being delivered to the facility. The shortening is pumped to silos downstream for storage. **(b)** The equipment used to test the quality of the delivery. Tests are conducted after drawing samples from the stream and following established procedures manually.

Measurements of the rheological properties of bakery shortening was carried out, by placing the OLR Series 1000 (OLR) in the pipeline that leads to the storage silo. The positioning of the OLR is shown in the image in Figure 2(a), in the area demarked by red border. A representative measurement of the storage and the loss moduli obtained over a range of 1 Hz to 100 Hz (6.28 rad/s to 628.3 rad/s) is shown in Figure 2(b). The figure shows that the elastic modulus (*G*') dominates the viscous modulus (*G*'') over the range of frequencies reported here. Although in some cases, the measurements in the lower frequency range were affected by ambient noise, the range covered exceeds data that are normally available from laboratory rheometer.

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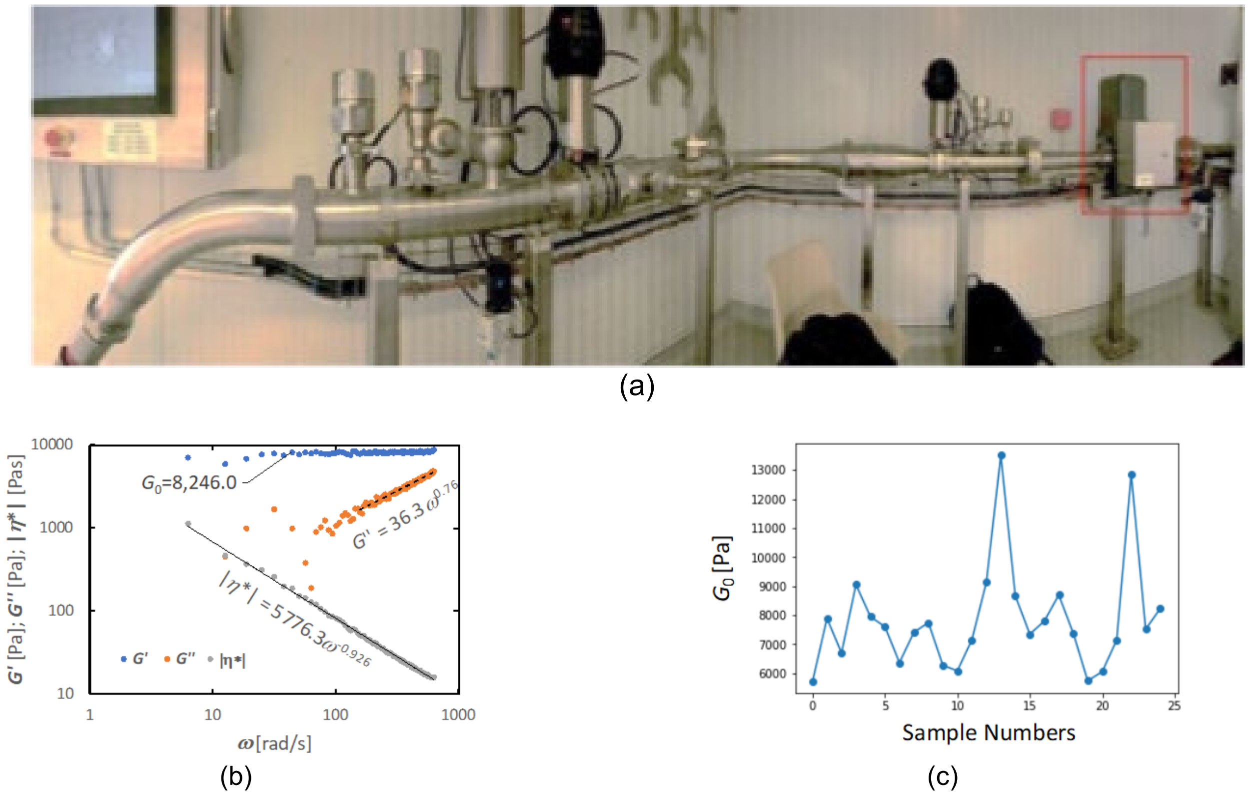


Figure 2

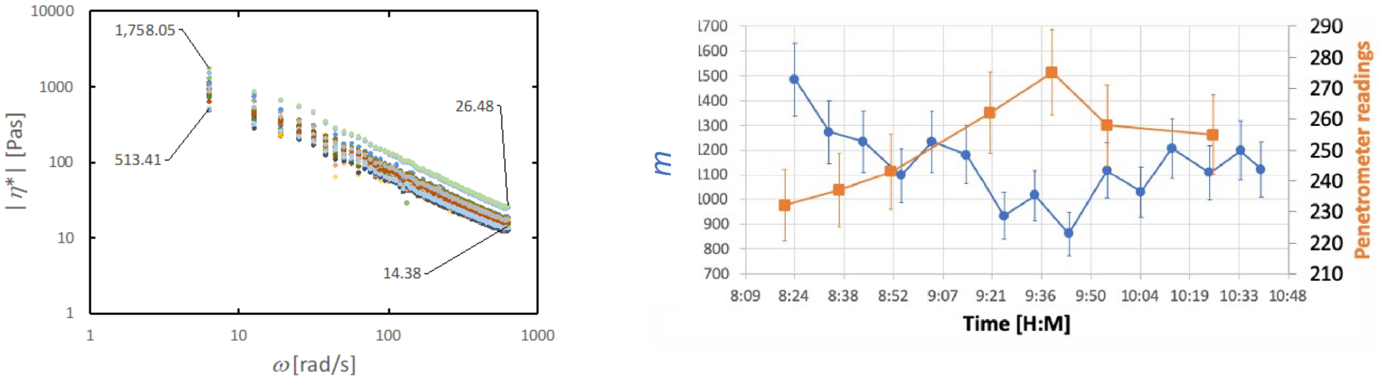
Figure 2. (a) Image shows the product pumped slowly through the delivery line where the OLR is installed (red bordered box) to the storage silos. (b) Typical measurement of rheology made by the OLR at 0.1% strain and at temperature of 23°C. (c) Variation of G_0 registered during measurement.

The measured data typically presented a minimum in G''. The plateau modulus G_0 was estimated as the value of *G*' at a frequency where the *G"* presented a local minimum. Since the *G*' remained almost insensitive to the changes in frequency beyond this point, the value of G_0 was used as a unique representation of the local order, and also correlates strongly to the yield stress, we track the G_0 value of the product over the time as the delivery was completed. The results are shown in Figure 2(c). The abscissa is sample numbers (timed), and the ordinate is the value of G_0.

We return to Figure 2(b) to point out that the complex viscosity obtained from these measurements can be represented by an equation of the form $|h^*|=mw^{-n}$. Measurement over the batch demonstrate that while the value of *n* remains almost constant over the batch, the value of *m* varies. In Figure 3(a) we plot the complex viscosity over the batch to demonstrate the effect of this variation. We find that the complex viscosity of the delivered sample changes over an order of magnitude within a single batch of delivery as shown in Figure 3(a). Since the $|\eta^*| = \sqrt{(G'/\omega)^2 + (G''/\omega)^2}$, It follows that both *G*' and *G*'' also vary, either individually or in unison, within the batch. This indicates local variation in fat microstructures which might be of interest from the standpoint of quality control.

Furthermore, we use the value of *m* to quantify the consistency of the material and compare this value with the measurements obtained using the drop cone penetration test using a standard penetrometer shown on the left-hand side image in Figure 3(b). These results are shown in Figure 2, with the blue data point representing the *m* values and the orange datapoints representing the penetrometer readings in arbitrary units.

We find that the *m* values correlate inversely with the cone penetrometer measurements that are independently obtained by a trained technician. This finding is expected because the higher the intercept value the "thicker" the product and the cone can penetrate to a lesser distance into the product before starting to creep or coming to a stop completely. This observation opens up a way of relating the measurements made in-line to those that are made off-line for quality control and serve as a de-facto standard for quality in the industry.



(a) (b)

Figure 3.

Figiure 3 (a) Variation in the magnitudes of the complex viscosity recorded by the OLR (b) Comparison of the *m* values with that of cone penetration readings. An inverse correlation is observed.

Conclusion

The results above demonstrate that the control of the quality of bakery shortening is possible using the OLR at to the extent similar to what is achieved by the manual methods already in practice. However, several other information, like the variations of G_0 or the values of $|h^*|$, that offer deeper insights into the microstructure of the product, and might be useful in finger-printing them, are also available in the OLR data.

This information is not readily available from penetrometer measurements. Therefore, with in-line rheology measurements, the quality control of bakery shortening during delivery can be automated and improved.

This approach offers real-time monitoring, precise control, and the ability to maintain tight control limits over the flow properties of the ingredient. It provides a viable solution for the challenges faced by the baking industry in terms of automation, ingredient diversity, food safety, and labour shortages.

OnLine Rheometer Pty Ltd
ACN 166 998 527

OnLine Rheometer Pty Ltd
Unit 9, 25 Perpetual Street
Truganina Victoria 3029
AUSTRALIA
Mobile Phone: +61 414 446 050
Office Phone: +61 3 5367 7477
Email: info@onlinerheometer.com
Website: www.onlinerheometer.com