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An Introduction to Food Friction, Lubrication & Wear

Overview

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- Tribology research in the food industry is becoming increasingly popular
- Studies have shown that the results of tribological testing can be related to sensory attributes of food such as creaminess, slipperiness and grittiness
- These properties are defining factors in the popularity of a product
- The high speed and low cost of tribological testing allows many more formulations to be tried and screened than is possible using more classical techniques like panel taste testing
- The results of testing can lead to improvements in flavour, mouthfeel and enjoyment of food; as well as consumer health by enabling testing of low-fat foods and foods that are easier to swallow
- Texture and mouthfeel are both absolutely critical perception parameters, but remain difficult to precisely quantify. For example, different versions of the same food group, such as high and low fat mayonnaise, often have the same bulk rheological properties (viscosity, dropping point etc). However, friction tests carried out on the MTM rig shows good discrimination between these products, which can then be directly related to their "feel and function".

This presentation gives and overview of tribology and the fundamental information required to understand the current state of tribology in food

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- Tribology overview
- Biotribology Applications & Benefits
- Useful tribology terminology and theory
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- Testing and quantification
- Examples of research
- Summary

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Tribology

"Tribos" : "rubbing" "ology": the study of

Tribology is the study of rubbing, or… "the study of things that rub".

- Coined by Dr. H. Peter Jost

1. *The science and engineering of friction, wear and lubrication*
2. *Study of interacting surfaces in relative motion*

Traditional tribology applications

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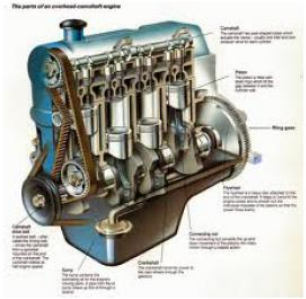

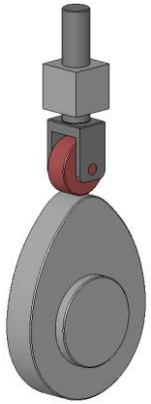

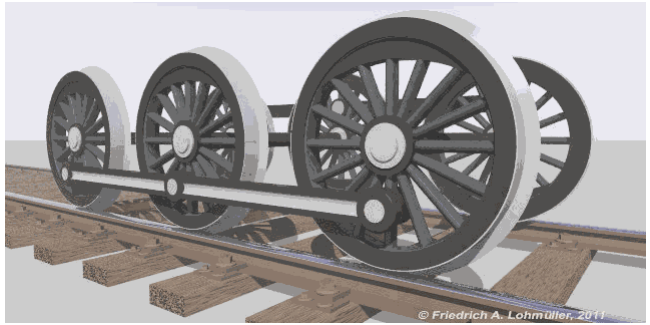

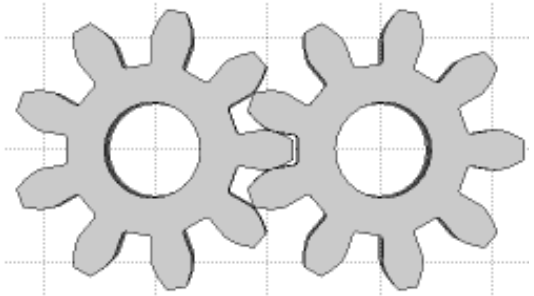

Benefits of traditional tribology research

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Measuring the friction and wear of a system and developing improved alternative materials and formulations leads to:

- Reduced costs
- Longer lasting systems
- Efficiency in use of resources
- Environmental sustainability
- Safer systems
- More reliable systems

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Biotribology

Biotribology applications

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Benefits of biotribology research

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Biotribological testing and investigation has enabled companies and researchers to:

- Develop low fat foods which still have the creaminess of full fat options
- Design foods that can be chewed and swallowed safely by those who might otherwise struggle, like the elderly
- Reduce the development cost of new foods and drink formulations (testing cheaper alternative ingredients and cutting down on costly panel testing)
- Optimise the taste, texture and mouth feel of foods and drinks
- Improve look and feel of products on our skin and hair
- Develop more environmentally friendly products
- Increase performance and longevity of artificial joints

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Useful Tribology terminology and theory

Slide/Roll Ratio (SRR)

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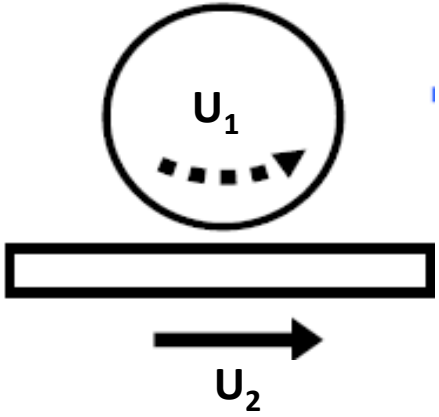
- A commonly used term to quantify the amount of sliding compared to rolling in a contact
- When testing you want the SRR of the machine to correlate with the ratio of sliding to motion in the real world application because the SRR affects the frictional response
- Therefore, being able to closely control and vary the SRR is vital to the testing process. With the MTM you can set the SRR to any value you choose and vary it as required.



Sliding speed= $|U_1 - U_2|$

Rolling speed= $\frac{1}{2}(U_1 + U_2)$

Slide to Roll Ratio (SRR) %= $200 \times |U_1 - U_2| / (U_1 + U_2)$

Pure Rolling (SRR=0%): $U_1 = U_2$

Pure Sliding (SRR 200%): $U_2 = 0$

Slide/Roll Ratio

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Sliding speed=

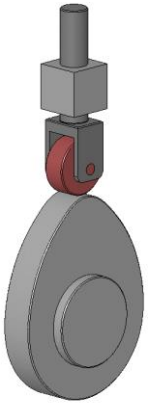
$$|U_1 - U_2|$$

Rolling speed=

$$\tfrac{1}{2}\,(U_1 + U_2)$$

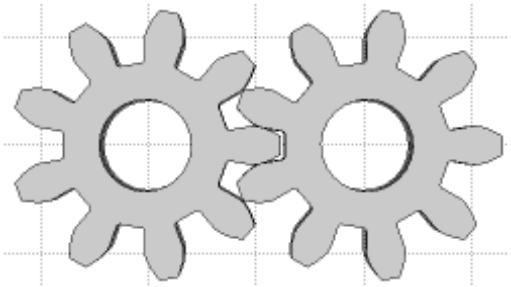
Slide to Roll Ratio (SRR) %=

$$200 \times |U_1 - U_2| \,/\, (U_1 + U_2)$$



50% SRR

200% SRR
Pure sliding



5% SRR

Varies during eating

Stribeck Curve

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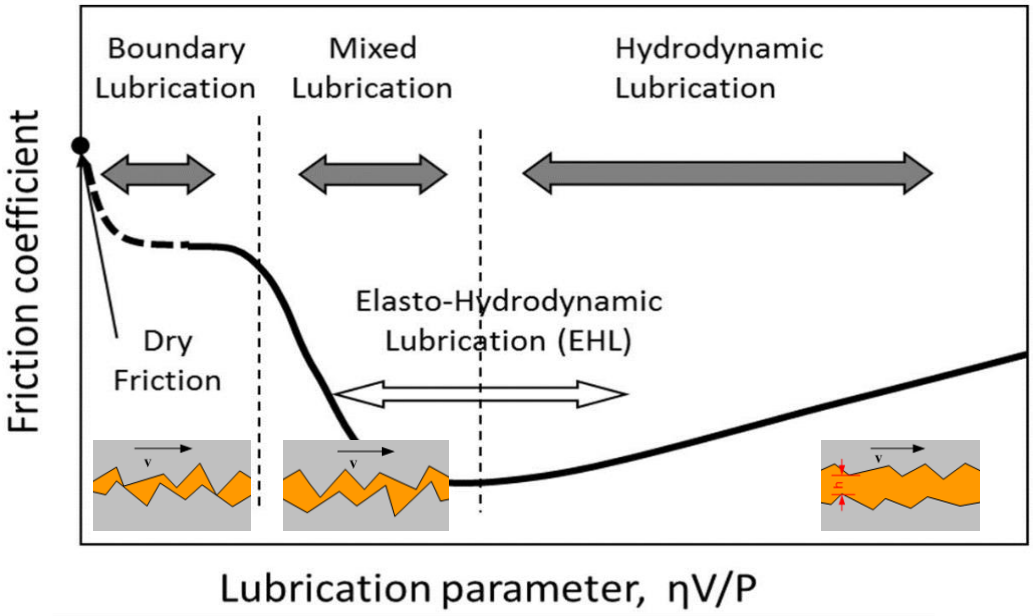
- A Stribeck curve is used to show how a lubricant performs in different lubrication regimes and how thick a layer of lubricant will be found at different conditions.

- This is particularly useful in more traditional tribology applications, where maintaining a layer of lubricant between parts is important.

- It is also useful in biotribology for a range of applications such as protecting artificial joints from damage.

- For food and beverage applications it is useful to compare formulations, because through the eating process the food or drink will behave much like a lubricant. This will also vary depending on the properties of the food or beverage.

- The film thickness is determined by the **speeds, SRR, viscosity, temperature, load and surface roughness**



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Food Oral Processing

Food Oral Processing

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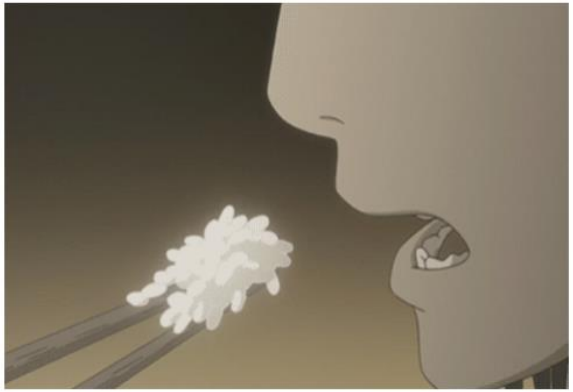
A destructive process involving deformation and breaking of food particles, resulting in constant changing of food status

Oral Actions

- Biting
- Chewing
- Tongue slapping
- Compression

Interacting surfaces in relative motion

- Gnashing teeth
- Tongue- teeth
- Teeth- food
- Tongue palate
- Tongue Food



Food Oral Processing

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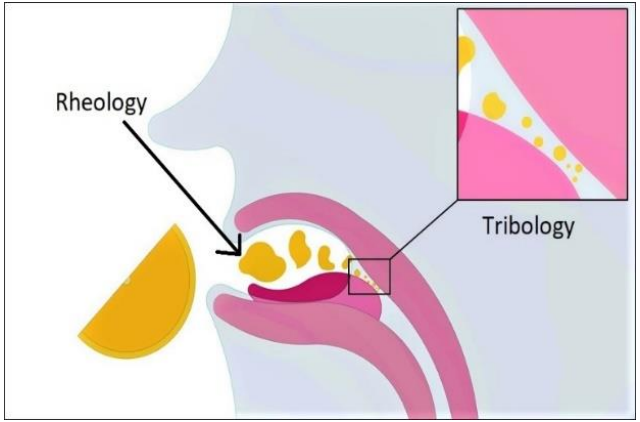
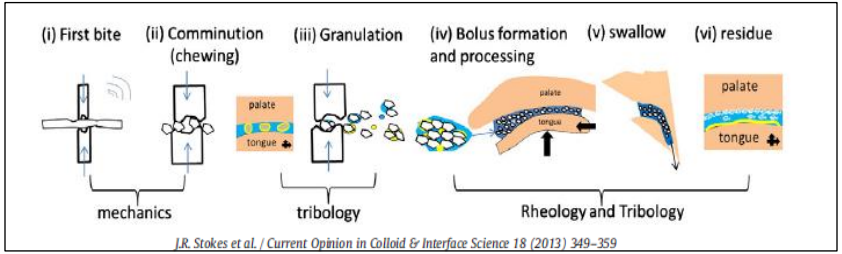
During the food oral process tribology plays an important role at many different stages:

- During the granulation of food particles (crushing/compressing of food) tribology is important in the avoidance of damage and sticking
- During bolus formation and swallowing the feel of the food being swallowed is determined by the tribological interaction between the food and the body.
- The feel and longevity of any residue is also affected by the tribology of the food

Using the MTM it is possible to quantify the way that food will interact with the body as it is eaten, and test and compare how formulations will feel at every step of the process



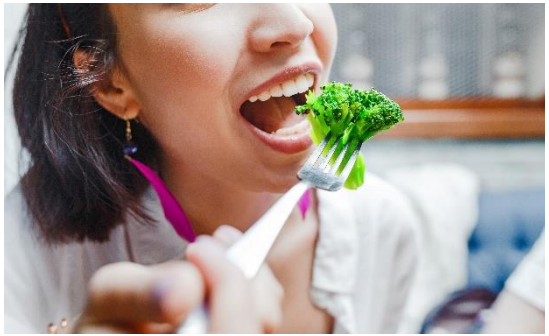


Sensory perception at a later stage of FOP could be very different from that at the beginning. **Hence rheological properties of food do not dominate texture perception throughout**

Sensory Perception

Mouthfeel- *'tactile (feel) properties perceived from the time at which solid, semi-solid or liquid foods or beverages are placed in the mouth until they are swallowed'*

- Mouthfeel is an important sensorial attribute.
- Along with taste and smell it determines the flavour of a food and the body's emotional response to eating it.
- Texture and mouthfeel play an important role in product acceptability and is often listed as a critical aspect in consumer choice of food or drink.
- Because of this, companies spend a significant amount of time and money testing every aspect of the foods or beverages they produce to try and create the most appealing product possible.



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Food Oral Processing – Testing and quantification

Sensory Perception – How it is tested

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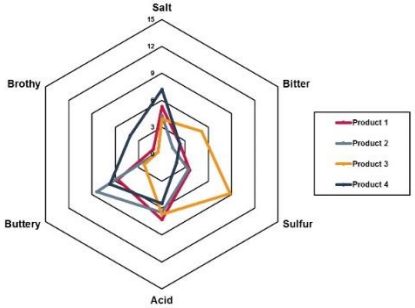

Historic techniques for quantification

- Historically, quantitative descriptive analysis (QDA) has been used to compare food and beverage formulations.
- This is a very costly and time consuming process where panel members use their senses to identify perceived similarities and differences in products.

Future techniques for quantification

- Using tribological test equipment, food and beverage manufacturers can screen many more formulations than would be possible using historic techniques.
- This allows companies to experiment with exciting and novel formulations, often with great success.
- If they wish, companies can then take the formulations that were shown in testing to be “best” (however they choose to define that) and panel test them should they wish to.
- By using the MTM, many companies have seen reductions in costs, research times and as a result have been able to compete more readily in the global market.

Food Tribology and sensory perception

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Table 1. Texture profiles based on rheology and tribology sensation mechanisms.

Dominating sensation regimes	Textural properties	Sensorial definition	Popular terms
Mechanics/rheology	Hardness	The force required to compress and to deform a food between teeth.	Hard, soft, firm
	Elasticity	The extent to which a compressed food returns to its original size when the load is removed.	Elastic, plastic
	Brittleness	The force at which the material fractures.	Brittle, crunchy, crispy, crumbly
	Cohesiveness	The strength of the internal bonds of food matrix.	Cohesive, crumbly,
	Chewiness	The energy required to chew a solid food until it is ready for swallowing.	Tender, chewy, tough
	Gumminess	The energy required to disintegrate a semi-solid food so that it is ready for swallowing.	Short, mealy, pasty, gummy
	Thickness, viscosity	The force sensed to deform a fluid food.	Thin, viscous, thick, consistent
Rheology/tribology	Particle size & shape		Gritty, grainy, coarse
	Particle shape & orientation		Fibrous, cellular, crystalline
	Juiciness		Juicy, watery
	Fat content		Greasy, oily
	Creaminess	Sensed smoothness of dairy foods.	Creamy
	Slipperiness	The force required for thin layer moving.	Slippery, smooth, rough
	Smoothness	The friction force sensed for relative surface movements.	Smooth, rough
Tribology	Astringency		Astringent

J. Chen, J.R Stokes, Trends in Food Science & Technology.,2012, 4-12

Tribology Instruments

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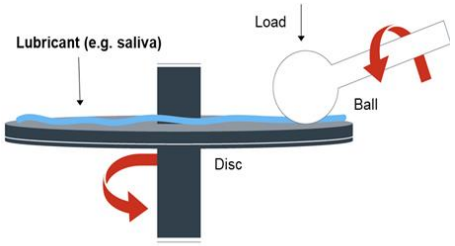
- Tribology instruments measure the friction and wear properties of semi-solid and liquid samples
- Test conditions can be set to closely mimic the conditions found inside the mouth (load, speed, SRR, temperature)
- Specimens are selected to represent the tongue and palate. PDMS is currently the most popular material for food oral processing testing due to its well defined surface properties and the correlation found between it and oral conditions
- The MTM has been used to test a range of properties of foods and beverages including:
  - Creaminess
  - Smoothness
  - Astringency
  - Afterfeel
  - Fattiness
  - Slipperiness
  - Roughness
  - Homogeneity



MTM Ball-on-Disc Schematic

PDMS Specimens & Sample in situ

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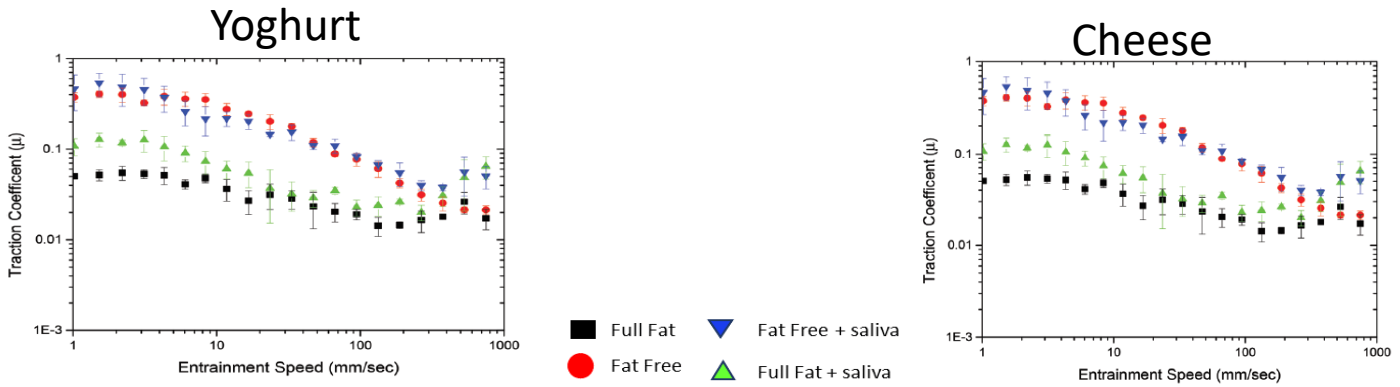
Examples of work using the MTM

Yogurt & Cream Cheese

In 2017, a team from the university of Leeds used the MTM as part of research investigating the relationship between rheological and tribological properties of dairy products. They found that they could accurately differentiate between the different types of yogurts and cream cheeses using the MTM.

The team concluded that through tribological testing in the presence of artificial saliva they can potentially “more accurately capture the dynamics of oral processing” and the data could be used to “unravel insights for texture and mouth feel perception” as observed by consumers.

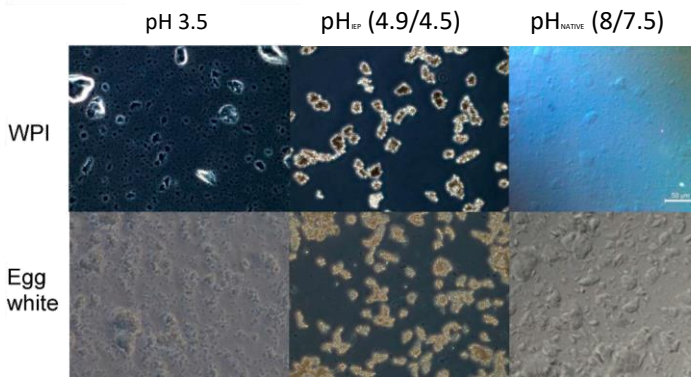


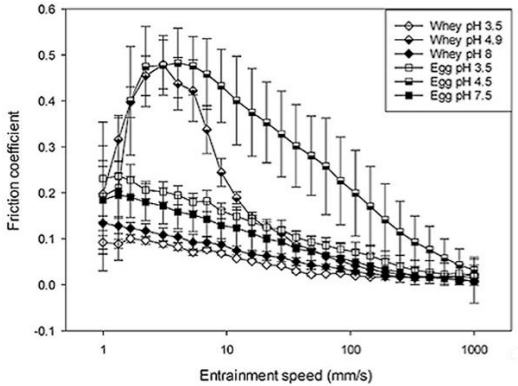
Laguna L, Farrell G, Bryant M, Morina A, Sarkar A, Relating rheology and tribology of commercial dairy colloids to sensory perception, Food & Function 2017, 8, 563

Developing low fat alternatives

Another exciting piece of research came out of the University of Birmingham this year. The research team there were focusing on finding a way for food producers to meet the growing customer demand for healthier foods (lower in calories) that still have a desirable creamy texture. Using the MTM they made a fascinating breakthrough.

They used the MTM to create Stribeck curves for their different sample fluid gels. These Stribeck curves can be seen below and clearly differentiate between the different formulations they used. From their testing, the researchers were able to recommend the whey protein isolate gel at 3.5pH as having the most potential of being a replacement for fats. The data from the MTM clearly supports this, showing the lowest friction coefficients throughout for this formulation.





Young P.W, Mills T.B, Norton I.T, Influence of pH on fluid gels produced from egg and whey protein isolate, Food Hydrocolloids, Volume 111, February 2021.

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Summary

Summary

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- Tribological study has proven to be very useful for understanding and quantifying a range of different aspects of mouthfeel
- This tribology research can be, and has been, used to aid the development of improved formulations, that have a more pleasant mouthfeel or lower calories, whilst reducing costs
- Researchers around the world are using the MTM to conduct tests at realistic conditions that mimic the food oral processing application
- Whilst tribological testing of foods and beverages is a relatively new field, it is an area in which a significant volume of research is being conducted. Companies are starting to realise the vast savings that are there to be made and are moving towards standardising tribology testing in their development process.
- The MTM has now established itself as the go to instrument for biotribological testing of foods and beverages due to its precision, accuracy and versatility; which allows researchers huge amounts of freedom in their investigations

For more information:

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