Boiled Egg
Republic of Korea

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1. Problem

Construct a torsion viscometer. Use it to investigate the differences in the 'viscous' properties of hens' egg that have been boiled to different extents.

2. Basic Idea

- Torsion viscometer
  - Device to measure viscosity using the fact that viscosity of liquid intervenes rotation of torsion pendulum.
  - Using this principle, it is possible to know the egg’s viscous properties without breaking it.

- Viscosity

\[ \tau = \mu \frac{dv}{dy} \]

\( \tau \) : Shear stress
\( \nu \) : Velocity
\( \mu \) : viscosity
\( y \) : depth
3. Experimental Setup

Aluminum cyllinder

Rotation Sensor

Spring (Making the periodic oscillation)

4. Theoretical Explanation

Liquid in the egg will make the oscillation damping.

Supposing an egg as an ellipsoid:

\[
\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \quad y = b\sqrt{1 - \frac{x^2}{a^2}} \quad A_{cylinder} = 4\pi xy
\]

\[F_{\text{viscosity}}(x) = A\mu \frac{dy}{dx} = 4\pi xy \mu \omega\]

\[
\int_0^a Fdx = \frac{4}{3} \pi a^2 b \mu \omega
\]

Theoretical Explanation cont.

Equation of damping oscillation of torsion device is:

\[1\ddot{\theta} + k\theta + b\dot{\theta} = 0\]

Resisting force in the damping oscillation is:
Energy loss in one period
(Energy damping)

- Energy damping
  - From the device
    - Device has toothed wheels, making the loss of energy proportional to its rotating amount = angular position change
  - From the egg
    - Expected to be proportional to \((\text{angular velocity})^2\), as is any damping oscillation.

\[-\frac{dE}{dt} = b\dot{\theta}^2\]

Inertia moment

1. Egg (assuming that it’s shaped like an ellipsoid)

\[ax^2 + y^2 = c \quad dm = \rho \pi r^2 dx\]

\[y = \sqrt{c - ax^2} \quad dl = \frac{1}{2} \rho \pi r^4 dx\]

\[I = \int_{\sqrt{c/a}}^{\sqrt{c/a}} \frac{1}{2} \rho \pi (a^2 x^4 - 2acx^2 + c^2) dx = \frac{8}{15} \rho \pi \frac{c^2 \sqrt{ac}}{a}\]

\[= 0.0000327 \text{kg} \cdot \text{m}^2\]

2. Device (cylinder)

\[I = 0.000651 \text{kg} \cdot \text{m}^2\]
### Solidification of egg

<table>
<thead>
<tr>
<th>Boiling time (sec. In 100°C water)</th>
<th>Thickness of solidified albumen</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>1.9mm</td>
</tr>
<tr>
<td>60</td>
<td>2.4mm</td>
</tr>
<tr>
<td>90</td>
<td>3.35mm</td>
</tr>
<tr>
<td>120</td>
<td>4.4mm</td>
</tr>
<tr>
<td>180</td>
<td>Complete</td>
</tr>
</tbody>
</table>

Viscosity: Same

Viscous property: Change (As amount of liquid changes)
General damping oscillation

- Damping Oscillation

Angle (deg)

All the damping oscillation

- Damping Oscillation with eggs boiled to various degrees
Analysis

- Energy loss from the device is proportional to the angular position change, as the toothed wheel in the sensor is the main friction source.

\[ \Delta E = 0.2398 \theta \]

Angular position change during one period (deg)

Analysis cont.

- Leaving out energy loss from the device, the one from egg remains to be proportional to \((\text{angular velocity})^2\) (Everything in 15°C)

Energy damping from the egg in one period (J)

\[(\text{angular velocity})^2\] mean value in one period (deg/s)^2
1. It is not proportional

2. Slightly boiled egg had less viscous effect than expected

**Why not proportional?**

- 0 sec. Boiled egg’s graph is:

A region: Too slow: Less energy loss from the device

B region: Almost same as expected

C region: Too fast: Albumen can’t follow the solid part: less viscous property than expected.

**Why less viscous than expected?**

Unboiled egg

30 sec. Boiled egg
Why less viscous than expected? Cont.

- Actual boiling process

“Viscous effect” of an egg when boiled to different extent

- Result

<table>
<thead>
<tr>
<th>Boiled time(s)</th>
<th>b</th>
<th>Viscosity, (relative viscous property)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.88e-5</td>
<td>1.457 Pa·s (1)</td>
</tr>
<tr>
<td>30</td>
<td>2.58e-5</td>
<td>(0.529)</td>
</tr>
<tr>
<td>90</td>
<td>1.90e-5</td>
<td>(0.389)</td>
</tr>
<tr>
<td>120</td>
<td>1.22e-5</td>
<td>(0.250)</td>
</tr>
<tr>
<td>150</td>
<td>7.32e-6</td>
<td>(0.150)</td>
</tr>
<tr>
<td>180</td>
<td>7.27e-6</td>
<td>(0.149)</td>
</tr>
</tbody>
</table>

Conclusion

- A torsion viscometer can be made using damping effect of viscous liquid.

- Measured viscosity
  - 1.457 Pa·s

- Egg is to solidify when boiled, making its viscous effect less.
  - Egg liquid is so sticky that some expectations are wrong about the egg
  - And as its solidification fixes yolk at particular position, make the egg much less viscous.