Sugar Capacity

An Introduction to AC Theory

This version of the problem has been adapted as a purely theoretical exercise as an introduction to AC Theory.

Intended Learning Outcomes

By the end of this activity students should be able to solve problems involving:

- Capacitance (and their effect in series and parallel)
- LCR circuits
- Inductance in a solenoid
- Dielectrics
- Parallel Plate Capacitors

KEYWORDS:

AC circuits, Capacitance, dielectric, electric current, electricity, inductance, LCR circuits, parallel plate capacitor, Q-factor, resistance, solenoid

Contents

The original version of 'Sugar Capacity' is run as a Laboratory Group Research Project for students on the Physics degree at the University of Leicester. It is undertaken by students in small groups. There are four laboratory sessions of 3 hours each as well as two facilitated workshops. For each of the workshops there is set question for class discussion, that are marked at the workshops. These workshop questions are designed to support the practical work by providing ideas and relevant theory. Most of the required theory can be found in any undergraduate physics text book.

The original version can be found at http://open.jorum.ac.uk/xmlui/handle/123456789/3335

Reading List

The following textbooks are suggestions, other equivalent textbooks are available:

- Breithaupt, J. ***Physics.*** Palgrave Foundations.
- Tipler, P.A. ***Physics for Scientists and Engineers***. Freeman.

Problem Statement

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Extracted from *Chocolate* by Michael Freemantle

WHAT'S THAT STUFF?

Can you imagine chocolate without science? Probably yes. Well, think again the next time you snap a bar of that delicious stuff. Although the preparation of top quality chocolate products may be regarded as an art form, modern processes for manufacturing the most popular brands rely heavily on science and technology.

The essential ingredient in all chocolate is cocoa beans. After harvesting, the beans are fermented in order to develop the chemical precursors of the chocolate flavour, then dried and transported to chocolate factories. At the factory, the beans are roasted and broken up into pieces called nibs. The nibs are then ground into chocolate liquor – a thick brown liquid that solidifies at about room temperature.

During processing, chocolate spends much of its time as a liquid. Viscosity, flow properties, and particle size are therefore important factors in chocolate manufacture. The next stage in chocolate manufacture involves cooling the liquid under controlled conditions to allow the fat, which holds all the solid sugar and cocoa particles together, to set in a crystalline form that has a smooth texture and appealing appearance.

From the documentation it is clear that the control of the size of sugar particles is important in chocolate manufacture. The Granada Chocolate Company is a small company in the Caribbean which might benefit from semi-automating the grinding process. To do this is it would be necessary to check the granularity of the sugar being introduced to the mix. It has been suggested by your research department that a simple way to check the granule size is to measure the bulk dielectric constant of the granulated sugar using an LCR circuit.

Your task is therefore to investigate if the granularity of sugar can be checked by determining its dielectric constant.

Suggested Deliverables

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Questions for Class Discussion

1. Derive an approximate formula for the inductance of a coil in terms of its physical dimensions, stating your assumptions. How does the inductance depend on the area of the coil and the number of turns? Explain this dependence in physical terms

2. Derive a formula for the capacitance of a parallel plate capacitor in terms of its physical dimensions. How does the capacitance depend on (a) the dielectric (b) the plate area (c) the plate separation? Explain this dependence in physical terms.

3. What is the resonant frequency ω of (i) an LC series circuit? (ii) an LC parallel circuit. Why do these have the same dependence on L and C?

4. How would you increase the Q-value of a circuit without changing its resonant frequency?

5. How does the rate of power dissipation change as the Q-value is increased for (a) a damped SHO, (b) a forced, damped SHO, (c) your LCR circuit?

6. The width of the resonance curve $\Delta\omega$ at resonant frequency ω_0 in a circuit with quality factor Q is given by which of the following:
   a) ω_0
   b) $Q\omega_0$
   c) ω_0/Q

   How can you explain this result?

7. The differential equation for a driven LCR circuit is

$$L\frac{d^2Q}{dt^2}+R\frac{dQ}{dt}+\frac{1}{C}Q=V_0\cos\omega t$$

   By analogy with a forced oscillation of a mass on a spring, what are the equivalents of mass, damping and resonant frequency?

8. Two capacitors C_1 and C_2 are in series. What is the overall capacitance? What is the capacitance if instead they are in parallel?

9. The circuit shows a plan to provide an audio signal to warn of changes in the dielectric constant of the sugar granules. What is the role of the rectifier in the circuit?