Gels in Daily Life

By Dr. Skip Rochefort
School of Chemical, Biological, and Environmental Engineering
Oregon State University
Skip.rochefort@oregonstate.edu

Gel Beads and applications to the Design of a Bioreactors, Bioprocess Units for Water Treatment, Drug Delivery and Artificial Organs

Overview

This activity introduces concept of polymers and gels, and relates this to engineering principles used to design ***biomedical devices*** (such as an artificial pancreas), ***bioreactors*** to produce high value products (such as pharmaceuticals) and ***filtration units*** to clean-up contaminated water (such as in an aquifer or lake contaminated with heavy metal wastes). Each of these are problems that *chemical, biological, and environmental engineers* encounter regularly in the working world, and each can have a significant impact on the lives of people everywhere.

Introduction to polymers and gels

A **polymer** is a long chain molecule with thousands of "repeat units" or mers (hence the name polymer, meaning many units). In this lab the polymer is called ***Sodium Alginate*** (Na-Alg) and it is extracted from *brown seaweeds*, the most prominent of which is ***giant kelp*** (*Macrocystis pyrifera*) harvested from the Pacific Ocean off the coast of California.. It is a product used in many foods as a thickening agent and *viscosifier* (something used to modify the viscosity of a liquid). We use a 2 wt% sodium alginate solution in water, which is similar in consistency to a shake at McDonalds or Burger King. Think about that when you get the "extra-thick" shake!

A **gel** is formed when the polymer chains are tied together (crosslinked). Imagine a 3-D spider web with water in all the empty space. Remember, the **gel beads are 98% water**! A gel has qualities of both solid and a liquid. Jell-O is one gel with which you are probably familiar, formed by heating the polymer gelatin to denature it and then cooling it to reform as a tangled network with hydrogen bonding. Sodium Alginate is chemically crosslinked using a calcium ion (see Figure Crosslinking and Gelation). Both Jell-O and the gel beads made here are in a special class of materials called ***hydrogels***, which are used extensively in the medical field for drug delivery, gel patches with medication embedded within them to be released upon contact with a wound, dressings for burn victims, artificial skin, etc.

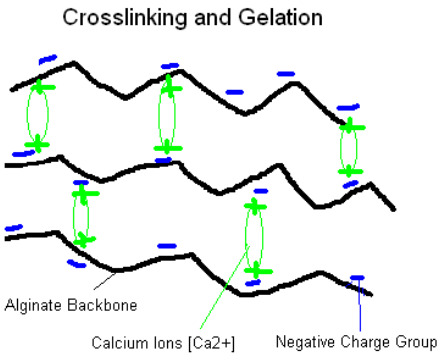

Figure 1 Crosslinking with Calcium ions to form a *HYDROGEL*.

Making Gel Beads
Making gel beads is a very simple process. It is as easy as dropping a 2 wt% Sodium Alginate solution (from an pipette or syringe) into a 1 wt% Calcium Chloride solution. Beads are formed because the drops are round (minimum surface area geometry) and *crosslinking* begins immediately once the Sodium Alginate hits the calcium chloride solution.

Diffusion is the process of the small molecules (such as the calcium ions) moving through the gel bead and slowly making their way to the center (imagine a colored dye diffusing through water). As the calcium reaches a sodium alginate molecule with an open negative site, it reacts there and makes a crosslink. This process continues until the liquid alginate core (uncrosslinked) becomes completely gelled and the bead becomes semi-solid (like completed Jell-O).

EXPERIMENT
1) Make gel beads as described above from the 2 wt% sodium alginate and 1wt% calcium chloride solutions supplied in lab. Use the different colors of sodium alginate to help with your experiment as needed.

2) Develop a *qualitative method* to determine the ***% gelation vs. time*** – the fraction of the bead that has formed a gel (or how much is still liquid) as a function of time. Keep good notes on your ***experimental method*** so you can describe it to someone later.

3) Sketch a plot of your experimental data of ***% gelation vs. time*** and try to explain in general phenomenological terms (not detailed chemistry) what is going on at the molecular level with both the calcium ion diffusing into the bead and the bead *crosslinking* (forming a gel).

Thought Questions (and maybe things you might want to check!).
1) Are all beads created exactly equal? What determines their size?
2) What is the effect of bead size on the results and what can be done to minimize these effects, if there are any?
3) What happens once the bead is removed from the calcium chloride – does the crosslinking stop immediately or does it continue over time? Why or Why not?
4) Does the mass or density of the bead change with increasing calcium ion content. If so, how much and is it measureable?
5) Why does the outer shell form so quickly but it take so long for the middle to solidify?
6) If you were designing a gel bead reactor, how long would you have to leave the beads in the calcium ion solution? How about if you were making an *Orbitz Drink* (or similar)?

Gel Bead Lab – NOTES

Sodium Alginate Information
- ***Sodium Alginate*** is a food grade polymer often used as a thickener, or more technically, a viscosifier (increases viscosity) in products such as fast food franchise shakes, puddings, drinks, salad dressings, etc.
- ***Sodium Alginate*** is extracted from giant kelp (a rapidly growing ocean weed), which is harvested in such areas as the Pacific Ocean off the coast of California.

- A **gel** is formed when the polymer chains are tied together (crosslinked). Imagine a 3-D spider web with water in all the empty space. Remember, the **gel beads are 98% water**! A gel has qualities of both a solid and a liquid. Jell-O is one gel with which you are probably familiar, formed by heating the polymer gelatin to denature it and then cooling it to reform as a tangled network with hydrogen bonding. Sodium Alginate is chemically crosslinked using a calcium ion (see Figure Crosslinking and Gelation). Both Jell-O and the gel beads made here are in a special class of materials called ***hydrogels***, which are used extensively in the medical field for drug delivery, gel patches with medication embedded within them to be released upon contact with a wound, dressings for burn victims, artificial skin, etc.

ENGINEERING APPLICATIONS

Biomedical Engineering

Design of an Artificial Pancreas

- Insulin is produced in the Pancreas by cells called *Islets of Langerhans* (islet cells) which produce insulin in response to a glucose stimulus.
- Using our gel bead production technique, if we mix islet cells in the sodium alginate solution (see above) they will become **encapsulated** in the gel beads. If we then incorporate hundreds of thousands of these cell-ladden gel beads into a semi-permeable sac, which could then be implanted in the body (and hooked-up by surgeons), we would have an **artificial pancreas**.
- Alternatively, we could build an external device with the sac of gel beads through which the blood could be circulated continuously (such as is done with kidney dialysis right now) as an another form of an artificial pancreas. This allows for easy replacement of the gel beads as islet cells die off or become inactive for some reason. This technology is currently being investigated in research labs around the world.

Bioprocess Engineering (also Chemical Engineering)

Design of a Bioreactor to Produce High Value Pharmaceuticals

- If in the example above, the islet cells are replaced by algae cells harvested off the coat of Oregon that are known to produce a high value pharmaceutical product, we can **encapsulate these algae cells** in the same way.
- These gel beads with algae can be placed into an **air-lift bioreactor** -- basically a vessel filled with growth media for the algae cells which is circulated by bubbling a gas through the solution (like in a fish tank), and which is usually clear so that light can be supplied to the growing algae.
- The algae grow rapidly, producing large quantities of the high value product, which is usually expelled into the outside liquid. After some time, this liquid is removed and the product is recovered by any number of extractive techniques, such as high pressure liquid chromatography (HPLC). In this way, the algae are stimulated to grow fast and produce much more recoverable product then would be possible by ocean harvesting techniques.

Environmental Engineering (also Chemical Engineering)

Clean-Up Of Contaminated Water

One amazing feature of the gel beads is that they "suck-up" a larger number of toxic materials, such as heavy metals and other pollutants.

A **packed-bed reactor** (beads packed into a vessel) or a **fluidized bed reactor** (essentially a bunch of beads in a vessel which are kept suspended by a liquid or gas flow through the vessel) can be used to clean-up many types of wastewater streams.

Examples

A gel bead fluidized bed is being investigated for clean-up of water on the NASA Space Station to enable water recycling (there isn't much water out there in space!).

An underground water supply (aquifer) that has been contaminated with heavy metal or nuclear wastes (think about the Hanford Nuclear site in the Richland, WA area) can be cleaned by passing the water through a gel bead packed or fluidized bed. The beads remove the contaminants, and when they have reached capacity, the gel beads are removed and dehydrated (remember they are only 2% solid when they are made), which leads to a much smaller amount for solid waste disposal. The process is extremely efficient because the water can simply be pumped from the contaminated aquifer, and either sent to a holding tank for processing as drinking or irrigation water, or simply placed back into the ground.