Super-absorbent Polymers for Natural Disasters

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Acknowledgments

We would like to thank Ms. Lai for answering our questions and supporting us throughout this project.

We would like to thank our peers for their encouragement during this year's science fair.

Timeline

October - Pick a topic
November - Decide sub-questions and start researching
January 5 - Research complete and start scientific report
January 30 - Finish scientific report
January 31 - Start on trifold
February 2 - Finish trifold
February 5 - Practice for presentation

What are super-absorbent polymers, and how can they be used to support our environment?

We wanted to do something environmentally focussed, and after hearing about super-absorbent polymers from our friend, it piqued our interest.

Sub-Questions

What are super-absorbent polymers?
How do they work?
How are they made?
What are the real-world applications of SAPs?
- How can they be used?
- What are the environmental impacts of SAPs?

What are the advantages and disadvantages of SAPs?
What are some current flood technologies and how effective are they?
What are some current drought technologies and how effective are they?
How do existing technologies compare to SAPs?

Problem

We believe that our current technologies for natural disasters such as floods and droughts are environmentally invasive and inefficient, especially in third-world countries. By using super-absorbent polymers, we hope to introduce a new way of dealing with floods and droughts that is more cost-effective and environmentally friendly.

Hypothesis

We hypothesize that the use of super-absorbent polymers can be a cost-effective, environmentally friendly option to deal with liquid-related natural disasters like floods and droughts. This is because super-absorbent polymers can absorb and retain large amounts of water - to help with floods, and can also slowly release water - to help with droughts.

Research

What are Polymers?

- Polymers themselves are the base of any living organism or non-living substance. They can be natural, for example, cellulose and DNA, or they can be synthetic, for example, nylon. The molecular structure of a polymer determines its physical properties.
- Linear polymers are macromolecules made up of repeating monomers, arranged in a straight line. They have a structure that resembles a string of pearls. Due to their simple structure, these polymers can pack tightly together and have a high density. Additionally, linear polymers have high boiling and melting points and are often considered strong and thermostable materials.
- Branched polymers are a type of macromolecule, that are synthesized by the polymerization of monomers. They resemble chains sprouting out of the main strand. Due to the branches, these polymers have a hard time condensing. As such, they have a low density, as well as low boiling and melting points.
- Cross-linked polymers have a molecular structure similar to that of a net. These polymers are stronger compared to their linear counterparts due to hydrogen bonding. This increases the melting and boiling points of the polymer, as well as their chemical resistance, due to the increased amount of effort it takes to break the hydrogen bonds. Cross-linked polymers are the structures that super-absorbent polymers have.

What are super-absorbent polymers (SAP)?

- super-absorbent polymers, abbreviated as SAPs, are polymers that can absorb large amounts of water. super-absorbent polymers are made from polyacrylate compounds, which are polymers that can soak up and retain large amounts of water.
- There are many different types of super-absorbent polymers. Among them, the most common ones are sodium polyacrylates, potassium polyacrylates, starch-grafted polymers, and polyacrylamide
- <u>Sodium polyacrylate compounds</u>: This is the most common type of super-absorbent polymer. They contain sodium ions which help with the absorption of water.

- Potassium polyacrylates: These polymers are developed specifically for plants, and they contain potassium ions instead of sodium ions. These make it safer for the environment because the potassium can be absorbed by the plants.
- Polyacrylamide Copolymers: These polymers gradually release water. Often used in agriculture to help plants during drought conditions
- Starch-Grafted Copolymers: Consists of natural starch and synthetic polymers. They're biodegradable
- Cellulose-Based Polymers: Made from cellulose, these SAPs are biodegradable (often have medical applications).

How do SAPs work

- Sodium polyacrylates are the most common super-absorbent polymers. They absorb water through osmosis. When in contact with water, the water moves into the polymer network, and the sodium ions leave the network, allowing more space for water. The cross-links that hold together the sodium polyacrylate polymer prevents the sodium from dissolving or breaking apart in the water. This polymer can absorb almost 800 times its mass in distilled water, but only 300 times its mass in tap water. This is because tap water contains sodium ions, so there is less sodium that has to leave the polymer to reach equilibrium.
- super-absorbent polymers have a porous, cross-linked structure which makes it easier to absorb liquids. The structure has a net-like shape and is held together by cross-linkers. These prevent the polymer from dissolving or breaking apart in water, by controlling the expansion of the polymer.
- super-absorbent polymers turn into a gel-like substance from a dry, granular, solid structure when it absorbs water, due to the formation of hydrogen bonds. When a liquid comes in contact with a super-absorbent polymer, the liquid is rapidly absorbed and distributed throughout the polymer's network.
- As the environment around the polymer dries, the polymer network shrinks, which forces the water out.
    - This can be applied in both droughts and floods. For floods, the external environment has a higher concentration of water compared to the inside of the polymer network, causing water to enter the network. For droughts, the polymer network has a higher concentration of water compared to its surrounding environment, causing the water to leave the polymer network.

- After the polymer is used, they are normally thrown out into a landfill, however, there are special cases where they can be reused.
- super-absorbent polymers contain hydrophilic molecules, that are attracted to water molecules. This helps the movement of water molecules into the polymer network
- Salt concentration also influences the absorption rate. Sodium polyacrylate compounds contain large amounts of sodium ions, which move out of the network, to reach equilibrium with the water. Meaning, that the fewer sodium ions available in the water, the greater the rate of diffusion. Water molecules enter the polymer network as sodium ions leave, to reach an even concentration in both substances.
- Inside the super-absorbent polymer, cations combine with the hydrophilic group. When the ion concentration outside the super-absorbent polymer is lower than the inside, the bound cation diffuses outward, which causes absorption
- How the super-absorbent polymers absorb:
    - Ion attraction - SAPs normally contain large amounts of ion groups (like sodium polyacrylate). These ion groups ionize in water, forming ions that attract the polar parts of water, and facilitating water molecules' entry into the polymer network
    - Hydrophilicity - Hydrophilic groups included in the structure of SAPs can form hydrogen bonds and other interactions with water molecules. The hydrophilic groups enhance the interactions (absorption) between water molecules and SAPs
    - Osmotic Pressure Effect - An osmotic pressure difference between the inside and outside of the SAP when it absorbs water. This is due to the high water concentration inside the polymer network. This pressure continues to attract water molecules into the polymer, which increases the absorption rate
    - Hydration Swelling - The SAP swells as the liquid is taken in and the polymer expands many times its size. The cross-links contain the expansion, which limits the amount of liquid the SAP can absorb. The cross-links of the polymer also ensure that the SAP doesn't dissolve in the water
    - Osmosis - SAPs (ex. Sodium Polyacrylate) absorb water via osmosis. When the sodium-containing polymer comes in contact with water, the sodium diffuses out of the polymer network to equalize the concentration of sodium inside and out of the structure. When the sodium leaves the polymer network, they’re replaced by water molecules. The water entering the

network causes the polymer to swell, and become gel-like. The cross-links that bind the polymer network together allow the SAP to keep its shape.

How are SAPs made?

- Methods of polymers synthesizing by creating long chains of monomers:
    - Polymerization/polymer synthesis: Process that synthesizes synthetic polymers through monomers chemically bonding together to form long chains.
    - The most common form of SAP is when acrylic acid and sodium hydroxide are combined in the presence of an initiator which forms a poly-acrylic acid.
- Uses heat or light as a catalyst to synthesize polymers
- SAPs are crosslinked linear hydrophilic polymers, which create a 3D polymer network/structure.
- Structures in SAPs
    - Polyacrylate compounds absorb and retain large amounts of water. Polyacrylate compounds are found in almost all SAPs
    - Crosslinkers bind the polyacrylate chains together to create a 3D structure. The less cross-links mean a looser structure and more room for water. More cross-links create a denser, less absorbent material.
    - Sodium ions help to enhance the absorption of SAPs by facilitating water movement in the polymer structure
    - Carboxyl groups (-COOH) ionize when they come in contact with water and become negatively charged, and this attracts water molecules

What are the real-world applications of SAPs?
→ How can they be used?

- super-absorbent polymers are used in diapers
    - The type of super-absorbent polymer used is sodium polyacrylate
- Personal hygiene products (pads): Can lock in around 300 to 500 times more water than the mass of the super-absorbent polymer
    - SAPs are not recommended for hygiene products because it may release harmful toxins (this may be based on bias)
- Biohazard absorption and protection: Traps and locks in water and similar fluids
- Wound care dressing: helps efficiently absorb water and other fluids

- Meat and fruit pads: Polymers are used to soak up the juices from meat and fruit (helps prevent leakage/keep the area clean and prevents microbes from developing)
- Ice pack: sodium polyacrylate can absorb large amounts of water and is good for cooling solutions
- Fake snow in movies: The polymer becomes a gel form after absorbing water which acts similarly to snow
- Reduce drought stress: Can help droughts by retaining water and releasing it when needed (in certain conditions the water absorbed will slowly be released)
- Retaining liquid waste: In landfills, super-absorbent polymers are essential for retaining wastewater for a long time (also helps remove these liquids faster in solid form)
    - Odor control: locks in foul odors from waste by absorbing the liquid and moisture
- Cable wrapping: prevents penetration of liquids from reaching the wires (forms a barrier when in contact with water)
- Flood control products: Effectively absorbs flood water and locks it in for transport (more efficient than regular sandbags)

What are the advantages and disadvantages of SAPs?

Cons:

<u>*Important Note → Bias: A manufacturer of a different product may downgrade the effectiveness of SAPs*</u>

- Manufacturing of SAPs could cause the workers to inhale dangerous chemicals (will impact health)
- Allergic reactions and skin irritation may result from direct contact (depending on skin type)
- Choking hazards and digestive problems when ingested (not child-friendly)
- When used for agriculture, it may accumulate over time which will potentially impact soil health
- *SAPs are <u>toxic</u> for both the environment and human health. Toxic for human health is debatable because once SAPs absorb water the toxins they release are not as detrimental to health as described in one of the sites.

→ **What are the environmental impacts of SAPs?**

- Most common super-absorbent polymers never biodegrade

    - In some cases such as biopolymers, these polymers are biodegradable and are not harmful to the environment. The absorption level may vary for these polymers because they may not be able to absorb and retain water, and they cannot biodegrade.
- They may also release carcinogens such as acrylamide and formaldehyde
- Since they are put into the landfill, they may prevent water from reaching plant roots and soil which could negatively impact the ecosystem (in a gel form)
- Could accumulate in soil which may impact soil health (then negatively impact the environment)

→ **Cost-effectiveness**

- Price varies depending on the manufacturer and type
    - Around $30 for a box/bag of 500 grams

    → **Accessibility**

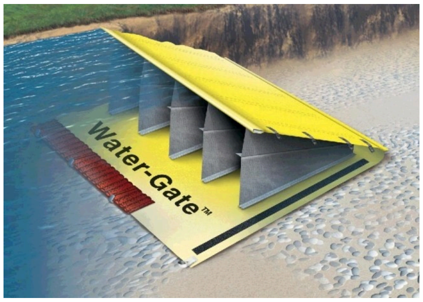
    - SAPs are fairly accessible because they are available on Amazon and many other locations and websites

Pros: (main pro: very absorbent and does not leak)

- Extremely absorbent
- Keeps water locked in (cannot be wrung out) for long periods of time
- Can reduce watering (Polyacrylamide Copolymers are made to gradually release water)
- Cost-effective and waste minimization
    - Reducing product changes because SAPs can be reused
- Prevents leakage - SAPs convert liquids into gel which cannot be wrung out supporting clean and effective usage (helps food packaging liquids)
- Safe disposal: since SAPs do not leak, they will not spill any harmful substances into the environment

What are some current flood technologies and how effective are they?

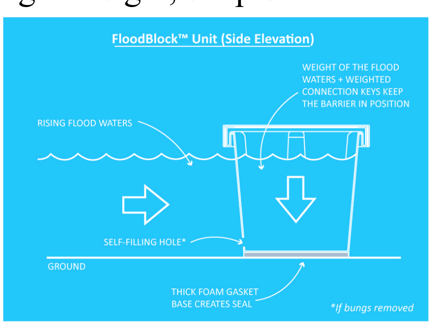
Watergate: Acts as a barrier by using the pressure coming from the water to stabilize itself *more expensive than sandbags (does not *dispose* of the flood water ← just acts as a barrier to separate the water from the property)



Water-inflated property protector (WIPP): Long tube barrier filled with water (very sturdy) ← protects homes from floods (effective as a barrier but does not dispose of the water)

Flood barrier socks (Quick dam): Small, sandless sandbags (efficient and easy to use) ← very popular *not practical for large floods

Modular flood prevention solution (flood block): Lego-like invention, environment-friendly (has a stacking feature that minimizes environmental footprint), light-weight, simple



Aquobex (heritage flood guard system): Used around homes near bodies of water (small floods), prevents water from entering the house

Sewage: (specifically storm drains) Storm drains help dispose of pooling waters on the road/sidewalk into underground pipes ← and prevent puddling on the streets

Sandbags: Diverts moving waters (when put correctly) ← simple but effective

Pumps/pails: Removes flood water but mainly used in flooded houses (not in the environment/on roads) ← small scale use

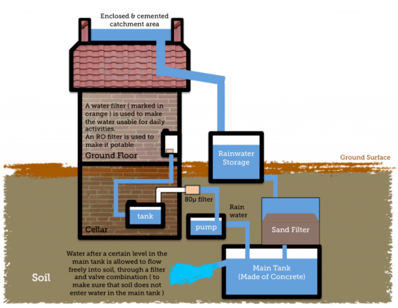
Sponge cities: Eco-friendly way of building a city where everything is able to absorb water and preserve the environment (very costly/large amount of energy and resources needed)

Summary: Most existing flood technologies only act as barriers for the water and do not actually dispose of it. We believe that SAPs will not only act as a barrier (when absorbing) but also dispose of the water where needed.

What are some current drought technologies and how effective are they (as well as other natural disasters)

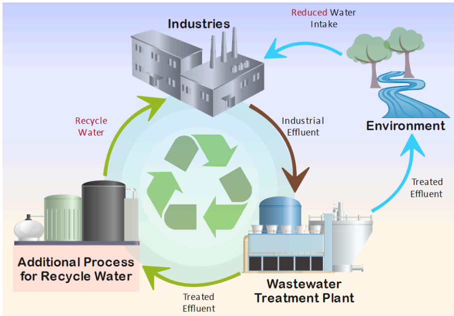
Desalination of Water: Since only 0.003% of the world's water is freshwater, desalinating water will help drought issues in certain areas. (+ 70% of the world is covered by water) ← needs a lot of resources and consumes a lot of energy (process: boiling → steam → condensation)

Rainwater Harvesting: Collects the water and stores it until it is needed during a drought



- Harvesting water from the air: Condensation → from moisture in the air

Wastewater Recycling: Complex system that rids wastewater of toxins and other contaminants → produces fresh water that is ready for use



Solar Pumps: Pumps out water from the Earth for irrigation while saving energy through the use of solar panels

Drip irrigation: limits water wastage, is cost-effective, ensures the right amount of water for plants to grow (preserves water but does not support environments where there is little to no water)

Summary: These technologies are not cost-effective and require lots of resources that many countries do not have access to. Using SAPs as a substitute for these solutions solves the problem of costs and resources due to its easy accessibility and cheap cost.

Follow-up questions:

1. How can super-absorbent polymers be effectively disposed of to ensure minimal environmental impacts?
2. How can we make super-absorbent polymers more environmentally safe?

Jot-Notes

How are SAPs made?

- Polymers are synthesized by creating long chains of monomers
    - Synthetic polymers are synthesized through processes called *polymerization or polymer synthesis* which is when monomers are chemically bonded together to form long chains
    - Acrylic acid and sodium hydroxide are combined in the presence of an initiator which forms a poly-acrylic acid. This is the most common form of SAPs.
- Uses heat or light as a catalyst to synthesize polymers
- SAPs are crosslinked linear hydrophilic polymers, which create a 3D polymer network/structure. They are made up of:
    - Polyacrylate compounds absorb and retain large amounts of water. Polyacrylate compounds are found in almost all SAPs
    - Crosslinkers bind the polyacrylate chains together to create a 3D structure. The less cross-links mean a looser structure and more room for water. More cross-links create a denser, less absorbent material.
    - Sodium ions help to enhance the absorption of SAPs by facilitating water movement in the polymer structure
    - Carboxyl groups (-COOH) ionize when they come in contact with water and become negatively charged, and this attracts water molecules
- They are classified by the type of polymer chain they contain
    - Sodium Polyacrylate - the most common type of SAP found. It can absorb many times its weight in water. It turns water into gel-like substances
    - Polyacrylamide Copolymers - These polymers gradually release water. Often used in agriculture to help plants during drought conditions
    - Polyvinyl Alcohol - PVA-based SAPs are known for their strength and abrasion resistance.
    - Starch-Grafted Copolymers - Consists of natural starch and synthetic polymers. They're biodegradable
    - Cellulose-Based Polymers - Made from cellulose, these SAPs are biodegradable (often have medical applications.
- SAPs have a porous, cross-linked structure, making it easy to absorb liquids.
    - The structure is held together by cross-linkers. The less there are, the looser the structure (allowing more space for water) and the more cross-links there are, the denser the structure (less space for water)

- SAPs turn water into gel-like substances by forming hydrogen bonds with water molecules
- SAPs contain hydrophilic groups that are attracted to water molecules
    - The hydrophilic groups bind salt ions easily
- When a liquid comes in contact with a SAP, the liquid is rapidly absorbed and distributed throughout the structure. This turns the SAP from a dry, granular, solid structure to a gel-like substance
- Electrostatic charges maintain the integrity of the structure and support the absorption
- Salt concentration also influences the absorption capacity and rate of the SAP
    - More salt = more water intake = more absorption. Less salt = less water intake = less absorption
    - The swelling ratio decreased as salt concentrations increased
    - Inside the SAP, cations combine with the hydrophilic group. When the ion concentration outside the SAPs is lower than the inside, the bound cation diffuses outward, which causes absorption
    - Distilled water (no salt/mineral concentration) increases absorption rate compared to saline (salt/minerals present) water
- Polyvinyl Alcohol: PVA-based SAPs are known for their strength and abrasion resistance.

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