Thermodynamic Engineering: The Irrigation Enigma

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THIS IS A MULTI-DAY LESSON

Arkansas Physics NGSS Suggestions:

Topic Three: Heat and Thermodynamics:

P-PS3-1: Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

Science and Engineering Practices: Developing and Using Models, Constructing Explanations and Designing Solutions (P-PS3-1)

Crosscutting Concepts: Cause and Effect (P-PS3-1)

Disciplinary Core Ideas: PS3.A Definitions of Energy (P-PS3-1)

Connections to the Arkansas English Language Arts Standards: SL.11-12.5

Connections to the Arkansas Mathematical Standards: MP.2, MP.4, HSM.Q.A.1-3.

P-PS3-1AR: Construct an explanation based on evidence of the relationship between heat, temperature, and the Kinetic Molecular Theory.

Science and Engineering Practices: Constructing Explanations and Designing

Solutions (P-PS3-1AR).

Crosscutting Concepts: Cause and Effect (P-PS3-1AR), Scientific Knowledge Assumes an Order and Consistency in Natural Systems (P-PS3-1AR).

Disciplinary Core Ideas: PS2.C: Stability and Instability in Physical Systems (P-PS3-1AR), PS3.B: Conservation of Energy and Energy Transfer (P-PS3-1AR).

Connections to the Arkansas Disciplinary Literacy Standards: RST.11-12.1, RST.11-12.9, WHST.9-12.2, WHST.9-12.8.

Connections to the Arkansas English Language Arts Standards: SL.11-12.2, SL.11-12.4, SL.11-12.5.

Connections to the Arkansas Mathematics Standards: MP.2, MP.4, HSN.Q.A.1-3.

P-PS3-4: Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

Science and Engineering Practices: Planning and carrying out investigations (P-PS3-4)

Crosscutting Concepts: Energy and Matter (P-PS3-4), Scientific Knowledge Assumes an Order and Consistency in Natural Systems (P-PS3-4)

Disciplinary Core Ideas: PS2.C: Stability and Instability in Physical Systems (P-PS3-4), PS3.B: Conservation of Energy and Energy Transfer (P-PS3-4).

Connections to the Arkansas Disciplinary Literacy Standards: RST.11-12.1, WHST.9-12.7, WHST.11-12.8.

Connections to the Arkansas Mathematics Standards: MP.2, MP.4, HSN.Q.A.1-3.

PS-ETS1-1: Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

Science and Engineering Practices: Asking questions and defining problems (PS-ETS1-1).

Crosscutting Concepts; Connections to Engineering, Technology, and Applications of Science: Interdependence of Science, Engineering, and Technology (PS-ETS1-1), Influence of Engineering, Technology, and Science on Society and the Natural World (PS-ETS1-1).

Disciplinary Core Ideas: PS3.D: Energy in Chemical Processes (PS-ETS1-1),

ETS1.A: Defining and Delimiting Engineering Problems (PS-ETS1-1).
Connections to the Arkansas Disciplinary Literacy Standards: RST.11-12.7, RST.11-12.9, WHST.11-12.8.

Connections to the Arkansas Mathematics Standards: MP.2, MP.4, HSN.Q.A.1-3, HSS.IC.B.6.

P3-ETS1-2: Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

Science and Engineering Practices: Constructing Explanations and Designing Solutions (P3-ETS1-2).

Crosscutting Concepts; Connections to Engineering, Technology, and Applications of Science: Interdependence of Science, Engineering, and Technology (PS-ETS1-2), Influence of Engineering, Technology, and Science on Society and the Natural World (PS-ETS1-2).

Disciplinary Core Ideas: ETS1.B: Developing Possible Solutions (P3-ETS1-2).

Connections to the Arkansas English Language Arts Standards: SL.11-12.4, SL.11-12.5

Connections to the Arkansas Mathematics Standards: MP.2, MP.4, HSN.Q.A.1-3.

P3-ETS1-3: Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Science and Engineering Practices: Asking Questions and Defining Problems (P3-ETS1-3).

Crosscutting Concepts; Connections to Engineering, Technology, and Applications of Science: Interdependence of Science, Engineering, and Technology (PS-ETS1-2), Influence of Engineering, Technology, and Science on Society and the Natural World (PS-ETS1-2).

Disciplinary Core Ideas: ETS1.A: Defining and Delimiting Engineering Problems (P3-ETS1-3).

Connections to the Arkansas Disciplinary Literacy Standards: RST.11-12.8, RST.11-12.9.

Connections to the Arkansas English Language Arts Standards: SL.11-12.4, SL.11-12.5

Connections to the Arkansas Mathematics Standards: MP.2, MP.4, HSN.Q.A.1-3.

Objective: Students will use critical thinking to engineer an alternate solution to the large amount of water loss farmers encounter when irrigating their crops.

Assessment: Students in a group will do a round robin of their engineering projects with physics calculations to augment their findings. Students will include overall rate of water retention/loss with subsequent cost.

Key Points: Diffusion, Newton's Law of Cooling, Heat Transfer Equations, Thermal Conductivity, Kinetic Molecular Theory and engineering projects.

Materials:

- Soybean Seeds
- Plastic containers (can be margarine tubs, yogurt tubs, cut 2L soda bottles etc.), at least four per group of four students (six plants in two for experimental and six plants in another two for control group).
- Potting soil (for optimum growth)
- Plastic straws glued together with consistent sized holes in them (to simulate a poly-pipe).
- Notebook for data collection
- Various materials for engineering design. Depends on student group.
- Humidity (or water) measurement devices.

Preparation:

Soybean plants work well for this lesson. They are easy to grow and sprout in about eight to ten days. Seeds can be obtained through the SSC on-line seed store (www.uaex.uada.edu/soywhatsup). Seeds are shipped out within a week of ordering. Students will need about a week to obtain materials for their engineering project. Another option is to have a set number of materials on hand for the whole class to use. Straws need to be glued and holes punched in them for use by students. Two straws per experimental and two for the control group should do it.

Time Duration:

Soybean plants take about a week to sprout so assume a week for the plants, a week for student brainstorming, planning and material acquisition (which can be done while waiting for plants to grow) and a week for building and experimenting. *Suggestion: to get the students invested in the lesson, have them plant the seeds in anticipation of the project.*

Teacher Note: *Ideas for designs could be different types of materials rather than plastic straws. Other ideas include insulating the straws, use thicker straws or make the holes smaller (reduce heat transfer). Another thought is to cool the water (increase the temperature difference). Students could also cover the straws and soil to increase condensation back to the soil.*

Elicit:

Start the lesson by telling students that substances change their temperature because heat has been added or taken from them. What is heat?" Heat is thermodynamic energy. So ask students, "What is the molecular nature of temperature? How does something change temperature or phase?" and then "How does the changing of temperature tie into the water cycle? What elements of the water cycle involve a change in phase?" Get students thinking about how the water cycle works (introduce Kinetic Molecular Theory, heat transfer equations and Newton's Law of Cooling) and its importance to plants by inquiring "How would these equations impact plants?" Students should mention water, its high specific heat and the water cycle as an essential for plant growth. Ask the question "How do plants receive water?" Comments such as rain, underground springs etc. will come up. Query the students, "If they are growing a garden, what will they need to do to ensure water is available for plants?" Irrigation should be the obvious response. Do a KWL chart about what students know about irrigation. Questions such as types of irrigation techniques and amount of water used should be addressed in the chart and stress how the Kinetic Molecular Theory (understanding the nature of temperature), specific heat of water (high compared to other solvents so a lot of heat is absorbed), conduction (irrigation water exposed to the atmosphere) and Newton's Law of Cooling (transfer of heat between the irrigation pipes and the water) all play a very important role in how effective irrigation is to a farmer's crops.

Engage:

Show the video *Irrigation for Agriculture* https://www.youtube.com/watch?v=24LJSJqpYuY to get students engaged in the project.

Explore:

Farmers have to be constantly aware of the amount of water they use to irrigate their crops. Water costs money and irrigation is a huge business when it comes to crop production. Farmers are always looking for ways to conserve water; lower water usage means less cost, better sustainability and less erosion.

It is the students' job to design and implement an alternative to current irrigation techniques. This will require groups to brainstorm a project, acquire the necessary materials, build the prototype and experimentally implement the prototype with soybean plants. *Student groups will be looking for an overall decrease of evaporation from the control group.* Have students brainstorm measurement ideas, however, some ideas for measurement can include using a humidity tester or drying the soil of both the control and experimental plants and calculating the difference. Students are to use Newton's Law of Cooling, Heat Transfer Equations and Thermal Conductivity equations if possible to support their findings. For instance, the use of a different type of irrigating pipe would change the thermal conductivity of the material and allow heat to be transferred faster or slower as a result. Once measurements and calculations are complete, student groups will present their findings in a round robin setting.

Explain:

Irrigation literally feeds the world. It has opened the doors for large crop production and multiple season growths. The downside to irrigation is it comes with a lot of water loss though evaporation. Evaporated water, while great for the water cycle, doesn't get to plants and this means more water is needed to add to crops. Increased water means more erosion, more runoff, an escalation of salts in the soil and an increase of cost to the farmer.

This would be a good time to cover the properties of water; its uniqueness (excellent solvation, dipole characteristics, different phases within a narrow temperature range, cohesion and surface tension, etc.) and its crucial role in life. Review the Kinetic Molecular Theory, Thermal Conductivity, Newton's Law of Cooling, and Heat Transfer Equations. Sample calculations for students to master are highly recommended.

$Q=mc\Delta T$

$Q=L\Delta m$

$Q/\Delta t=-kA\,(\Delta T/\Delta x)$

$dQ/dt=-hA\Delta T$ *(optional)*

There are several types of irrigation. The most common are surface irrigation (such as water running in ditches between rows), sprinkler systems and poly-pipe irrigation (pipes with holes in them run down rows to reduce evaporation and get water to the plants at the spot). Of the three, poly-pipe is the best for water conservation but can we do better? Can an alternative irrigation method be found that decreases evaporation to a lower level than poly-pipe?

Elaborate:

Break the students into groups and, based on what was seen on the video and what was just covered, have the students do literary research on different irrigation techniques. Students should include research on how to manually decrease evaporation through engineering a way to block water loss. Students should come up with a research question, hypothesis and engineering plan. If the engineering plan is doable and measurable, then a student group can try it. Students will need to present how they built their prototype and its success or failure at reducing water loss from evaporation compared to the poly-pipe irrigation at the end of the lesson with physics calculations, if possible, to support their findings.

Research website suggestions:

https://www.uaex.uada.edu/publications/pdf/mp197/chapter8.pdf

https://www.uaex.uada.edu/media-resources/news/june2017/06-21-2017-Ark-surge-irrigation-fact-sheet.aspx

https://www.uaex.uada.edu/counties/greene/docs/AG-files/22-29-irrigation-tools-beds-project.pdf

https://www.uaex.uada.edu/media-resources/news/november2015/11-06-2015-Ark-Poly-pipe-cost-share.aspx

http://www.fao.org/docrep/T7202E/t7202e08.htm

https://www.uaex.uada.edu/media-resources/news/november2015/11-06-2015-Ark-Poly-pipe-cost-share.aspx

https://owlcation.com/stem/5-Properties-of-Water

https://www.uaex.uada.edu/publications/PDF/FSA-9512.pdf

Evaluate:

Students will do a round robin about their findings, presenting their engineered prototype and their data collected with supporting calculations from the engineering experiment. A research paper on the prototype and a reflection paper on what they learned will be handed in by each student.

Extend:

End the lesson with how evaporation and the thermal properties of water have huge impacts on our food supply.

After the round robin, have students debate their project's success in comparison to other projects in the classroom. Have the students do an economic impact paper on water savings using their engineering project.

Have a local farmer do a presentation in the classroom of the impact irrigation has on crops and the costs involved with irrigation.

Have the class do a presentation of their findings at the local County Extension Office.

Teacher Note: Need help with the physics in this lesson? Dr. Daniel Young, assistant professor of physics at the University of North Carolina-Chapel Hill is the academic support behind the physics in this lesson and is willing to answer any questions. You can email him at dyoung4@email.unc.edu .