Thermoelectric Generator inquiry-based lessons and activities

The thermoelectric generator investigation has been adapted from an inquiry-oriented learning activity originally conceived and produced in the Faculty of Science at the University of Technology, Sydney. The investigation has been developed in collaboration with the Department of Education.

Lesson Overview

> *It is estimated that somewhere between 20% to 50% of industrial energy input is lost as waste heat in the form of hot exhaust gases, cooling water, and heat lost from hot equipment surfaces and heated products.*

Waste Heat Recovery: Technology and Opportunities in U.S. Industry US Department of Energy, 2008

Australia's energy needs have been largely met by fossil fuels, with coal and gas accounting for 91 per cent of Australia's electricity generation. Waste heat is produced by processes that use energy and as such, is a by-product of electricity generation, industrial processes, cars and trucks, and domestic appliances such as refrigerators and air conditioning units. Additionally, human activities, natural systems and all organisms produce waste heat.

There is a growing need to use renewable sources of energy which produce less waste heat and are sustainable. Waste heat recovery units (WHRU) can be used to recover waste heat from camping stoves, cars, engines and microchips.

Possible Stage 4 NSW Science Syllabus for the Australian Curriculum outcomes

PW4 – Science and technology contribute to finding solutions to a range of contemporary issues; these solutions may impact on other areas of society and involve ethical considerations. (ACSHE120, ACSHE135)

Students:

(a) identify that most energy conversions are inefficient and lead to the production of heat energy, eg in light bulbs

(b) research ways in which scientific knowledge and technological developments have led to finding a solution to a contemporary issue, e.g. improvements in devices to increase the efficiency of energy transfers or conversions

(c) discuss the implications for society and the environment of some solutions to increase the efficiency of energy conversions by reducing the production of heat energy.

Possible Stage 5 NSW Science Syllabus for the Australian Curriculum outcomes

PW4 - Energy conservation in a system can be explained by describing energy transfers and transformations. (ACSSU190)

Students:

(a) apply the law of conservation of energy to account for the total energy involved in energy transfers and transformations

(b) describe how, in energy transfers and transformations, a variety of processes can occur so that usable energy is reduced and the system is not 100% efficient

(c) discuss, using examples, how the values and needs of contemporary society can influence the focus of scientific research in the area of increasing efficiency of the use of electricity by individuals and society (ACSHE228, ACSHE230)

ES3 - People use scientific knowledge to evaluate claims, explanations or predictions in relation to interactions involving the atmosphere, biosphere, hydrosphere and lithosphere.

(ACSHE160, ACSHE194)

Students:

(d) evaluate scientific evidence of some current issues affecting society that are the result of human activity on global systems, e.g. the greenhouse effect, ozone layer depletion, effect of climate change on sea levels, long-term effects of waste management and loss of biodiversity.

Background Information

A thermoelectric generator (TEG) is a solid-state device which is able to convert heat energy to electrical energy. The TEG which you have been given is a semi-conductor sandwiched between two ceramic plates and contains negative and positive terminals. There is a *hot side* where heat is rejected and a *cold side* where heat is absorbed.

Heating one end of a thermoelectric material causes the electrons to move away from the hot end toward the cold or cooler end. An electrical current is produced when electrons move from the hot side to the cooler side. The larger the temperature difference the more electrical current is produced and therefore more power is generated.

As the hot side is heated, the cold side of the generator heats up. In order to generate power with the thermoelectric generator you need both a heat source and a way of dissipating heat in order to maintain a temperature difference across the thermoelectric materials.

Thermoelectric power results primarily from two physical effects: the Seebeck effect, and Peltier effect.

The Seebeck effect

The Seebeck effect is the conversion of temperature differences directly into electricity. The Seebeck effect is named after Thomas J. Seebeck, who first discovered the phenomenon in 1821. Seebeck noticed that when a loop comprised of two dissimilar materials was heated on one side, an electromagnetic field was created. He noted that the strength of the electromagnetic field, and therefore the voltage, is proportional to the temperature difference between the hot and cold sides of the material.

The Peltier effect

The Seebeck effect can be reversed by running a current through the TEG. This effect creates a temperature difference in the TEG (heating or cooling).

This thermoelectric effect is called the Peltier effect and was first discovered in 1834 by Jean C.A. Peltier, for whom it was named. Peltier discovered that whenever a circuit of two dissimilar materials passes current, heat is absorbed at one end of the junction and released at the other. This process forms the basis for thermoelectric cooling and temperature control; these are currently the widest applications of thermoelectric devices.

Classroom activities

These series of activities are set out using an inquiry based approach by incorporating the 5Es – engage, explore, explain, elaborate and evaluate. There is also scope for extension.

All activities can be scaffolded by the teacher to suit the context of their class. Investigations are aimed to be student centred whereby students inquire and outline a logical procedure and can be adapted.

Engage

1. Lesson can begin with students watching: https://www.youtube.com/watch?v=79fNvjjgxPM

   Other videos, digital media or print media can be substituted or used collaboratively to engage students in discussion. This opening activity should elicit conversation and ideas about energy and energy usage.

   (a) Lightbulb infographic
   http://awesome.good.is/transparency/web/1012/lightbulb/transparency.jpg

   (b) On track for carbon pollution targets information and infographics
   http://www.wwf.org.au/?9980/key-countries-on-track-to-meet-international-obligations-australia-far-off-track

   After the video, the teacher facilitates discussion about Australia's use of energy, sustainability and effects of energy use, such as relative amounts of pollution and waste heat.

2. Students consider how waste heat affects their everyday lives. Students work in pairs to identify three domestic sources of heat.

Explore

1. Student use secondary sources to research the energy efficiencies of different types of bulbs.
2. Students augment their research by investigating waste heat in a variety of light bulbs including incandescent, fluorescent, halogen and LED by collecting, recording and comparing data about:

   - the amount of light produced
   - the amount of heat (temperature produced)

   Students discuss the efficiencies of current light sources as possible sources of indoor/outdoor waste heat.

3. Student use secondary sources to research the energy efficiencies of different types of energy, including coal, gas, solar, wind, and other relevant energy sources.

Explain

1. Students summarise what they have learnt about sustainability.
2. Students define waste heat and sources of waste heat within the home/school and within industry such as in factories and the use of fossil fuels. Students discuss possible solutions to getting rid of waste heat or using it to be efficient and sustainable.

   (a) Student research and explain waste heat recovery units (WHRU), including TEGs.

   - Types of TEGs, including Radioisotope Thermoelectric Generator (RTG) used to power satellites and the Mars Curiosity Rover.
   - Current uses of TEGs for creating sustainable machines. Engineers at BMW are working with NASA scientists to use TEGs to generate 200W to power BMW's electric engine.
3. Students draw posters to promote awareness of waste heat in the science lab and within other classes e.g. technology, hospitality. Students can incorporate a TEG device in their presentation and how it can be used or promoted.

Elaborate/Extend

1. *Demonstrations*: teachers can demonstrate the use of TEGs to show how electrical energy is produced by applying two different temperatures to the sides of the TEG. This can be achieved by connected the leads of the TEG to a low powered device such as an LED (diode).

   The teacher can demonstrate the different effect varying temperature differences has on the output of electricity. Electricity output can be determined using analogue equipment such as voltmeters and ammeters, as well as digital equipment including data loggers and smartphones. Similarly, temperatures can be recorded and determined using thermometers or infrared non-contact thermometers, if available.
2. *Student Challenge: generate the highest output power from a TEG fuelled by waste energy.* This investigation is intended as an open ended inquiry activity whereby students engage in finding out how to best create the highest voltage output from sources of heat.

Student Challenge – I've got the power!

Part 1

1. Setup a TEG with the hot source and measure the power it delivers to a 2 Ω load (i.e. R = 2 Ω).
2. Discuss how you might increase the power the TEG delivers.
3. Communicate your preliminary findings of power to the class along with ideas you have for increasing the power.

Part 2

1. Proceed with investigation to maximise the output power.
2. Record the method you used and the reason(s) for choosing that method.
3. Record your data (e.g. of the power delivered to a load).

Optional Student Challenge - Water Fan

This experiment can be used as an extension activity for students to engage with TEGs and attempt to create practical applications. Extra apparatus can be sourced by the school.

1. Students are given a TEG, low-voltage fan, pieces of metal (metal type can be investigated as a variable – copper, aluminium, iron, nickel, etc.) and two beakers of hot and cold water.
2. Students set up the equipment to generate power to make the fan work.

Tips to produce a meaningful power output

There are two critical factors that dictate power output:

1. The amount of heat flux that can successfully be moved through the module (heat flow). The greater the amount of heat the more power can be produced.

   Examples of sources of heat include:

   - Candle (amount of power that can be produced is limited)
   - Bunsen burner
   - Wood fire
   - Electric stovetop
   - Warm sand
   - Hand warmers

2. *Temperature* – the temperature of the hot side less temperature of the cold side (ΔT).

   Great effort must be placed on both the heat input design and especially the heat removal design (cold side). The better the TEG system construction is at moving heat from the hot side to the cold side and dissipating that heat once it arrives to the cold side, the more power will be generated. Thermally conductive materials include:

   - Aluminium (e.g. heat sinks)
   - Copper
   - Water (i.e. moving liquid on the cold side)

There should to be consideration of energy conversion, for example, given a 5% energy conversion, 100 watts of heat would need to be exposed on the hot side to produce 5 watts of power. This requires 95 watts of heat to dissipate on the cold side continuously as only 5 watts is being converted to power.

Students can extend their investigation by considering how they can evaluate their method if they had access to other sources of heat or technologies which could expose or dissipate heat e.g. water pump coolant (similar to CPU coolants), liquid nitrogen, dry ice.

Evaluate

1. Students create online quizzes about sustainability, waste heat and TEGs.
2. Students present the results of their experiments to the class.

Extension

1. Investigate the Seebeck coefficient. The magnitude of the Seebeck coefficient (S) varies with material and temperature of operation. The Seebeck coefficient is thus defined as:

$$S = -\frac{\Delta V}{\Delta T}$$

   Where

   - S is the Seebeck coefficient
   - ΔV is the change in thermoelectric voltage
   - ΔT is the temperature difference between the two side