VG100: INTRODUCTION TO ENGINEERING

Thermal Engineering

Dr. Qiang Zhang

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Preview

- Combustion (Invited talk by Prof Lipo Wang)
- Thermal energy & power generation
- Thermoelectric Power Generation
- Introduction to Conduction

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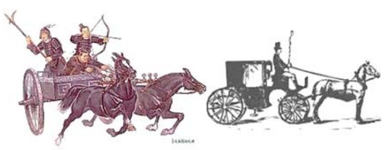
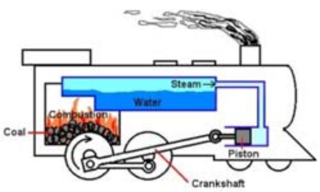
Revolution in Engineering





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Steam Powered…

(1769)

(1886)

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Steam Powered…

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Thermal power generation

Heat sources: coal, nuclear, solar, biofuels, etc.

- Efficiency is governed by the laws of thermodynamics.
    - low 40% - 62%

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Thermal engineers are in great need!

Year	2001	2050	2100
Global population (in billions of people)	6.15	9.4	10.4
Global energy consumption, TW	13.5	27.6	43.0

- Energy and water head the list of humanity’s top 10 problems and 21st century innovation topics.

- Smalley R. E. Future global energy prosperity: the terra-watt challenge. *MRS Bulletin*. 2005. Vol. 30. No. 6. P. 412–417.
- 5. Meieran E. S. *Predicting Challenges of the 21st Century*. Materials Engineering Impact, Purdue University, West Lafayette, IN, USA, 2006. P. 8–9.

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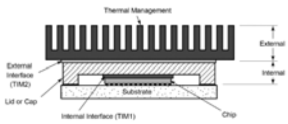
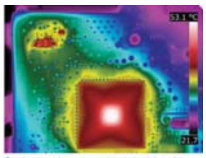
New challenges to next generation thermal engineers:

- Better understanding of the fundamentals!
- Multi-disciplines

Areas to contribute:

- promote new efficient energy conversion concepts
- Energy friendly building systems (“net zero energy building”)
- Renewable energy utilization.
- New technological challenges





Overheating element on printed circuit board

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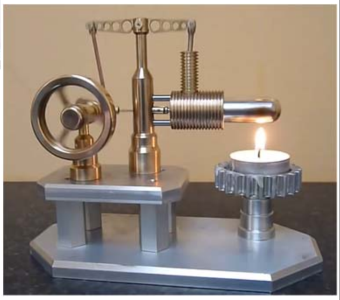
Stirling Engine

1816, the first working hot air engine



Entropy, again…

Cold Temperature

Hot Temperature

- The more possible micro-states in a macro-state, the higher the entropy. The configuration with the highest entropy (i.e. the most micro-states) is the most probable.
- **Energy is always spreading out as entropy will always increase!**

"The increase of disorder or entropy is what distinguishes the past from the future, giving a direction to time." - *Stephen Hawking*

Entropy, again…

Cold Temperature

Hot Temperature

- What if you spin the wheel?
- Will this be against the 2nd law?

Back to our lab …

The Seebeck Effect

- Thomas Seebeck (1821) found that an electric current would flow continuously in a closed circuit made up of two dissimilar metals, if the junctions of the metals were maintained at two different temperatures.

- Seebeck Coefficient:

  S= dV / dT

- If these materials had been used at that time to construct a thermoelectric generator, it could have had an efficiency of around **3%** - similar to that of contemporary steam engines

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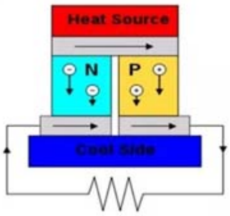
The Seebeck Effect

The good thermoelectric materials should possess

1. Large Seebeck coefficients   S= dV / dT
2. Electrical conductivity ?
3. Thermal conductivity ?

- Thermoelectric power generation (TEG) devices typically use special semiconductor materials, which are optimized for the Seebeck effect.



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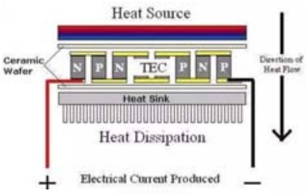
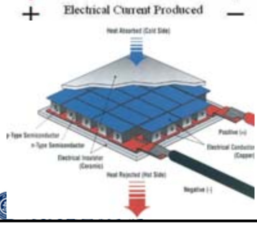
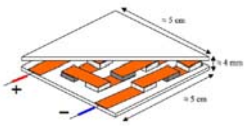
Thermoelectric power generation (TEG)







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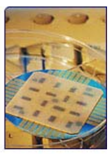
Thermoelectric power generation (TEG)



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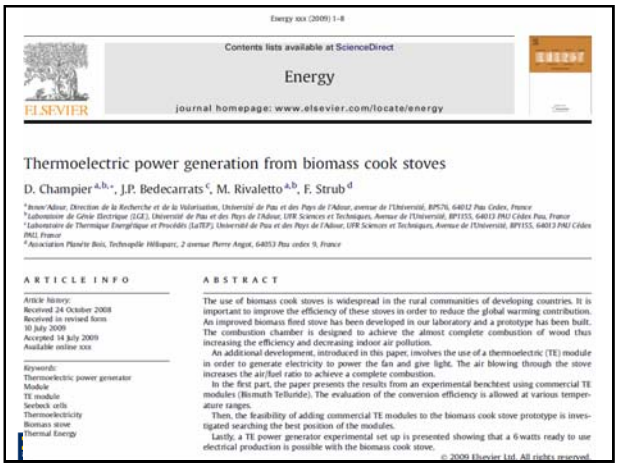
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Thermoelectric power generation from biomass cook stoves

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ABSTRACT

The use of biomass cook stoves is widespread in the rural communities of developing countries. It is important to improve the efficiency of these stoves in order to reduce the global warming contribution. An improved biomass fired stove has been developed in our laboratory and a prototype has been built. The combustion chamber is designed to achieve the almost complete combustion of wood thus increasing the efficiency and decreasing indoor air pollution.

An additional development, introduced in this paper, involves the use of a thermoelectric (TE) module in order to generate electricity to power the fan and give light. The air blowing through the stove increases the air/fuel ratio to achieve a complete combustion.

In the first part, the paper presents the results from an experimental benchtest using commercial TE modules (Bismuth Telluride). The evaluation of the conversion efficiency is allowed at various temperature ranges.

Then, the feasibility of adding commercial TE modules to the biomass cook stove prototype is investigated searching the best position of the modules.

Lastly, a TE power generator experimental set up is presented showing that a 6 watts ready to use electrical production is possible with the biomass cook stove.

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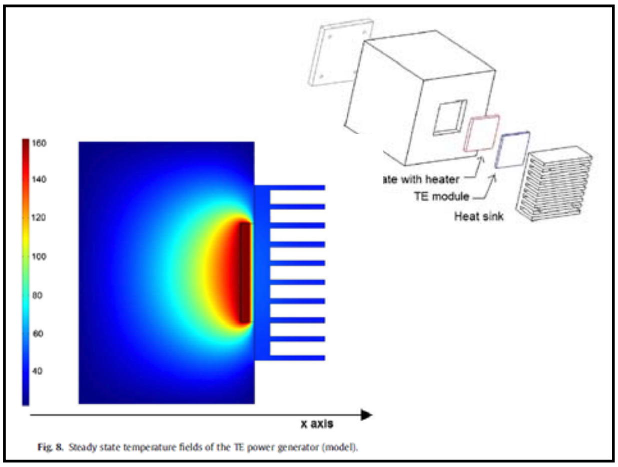

Fig. 8. Steady state temperature fields of the TE power generator (model).

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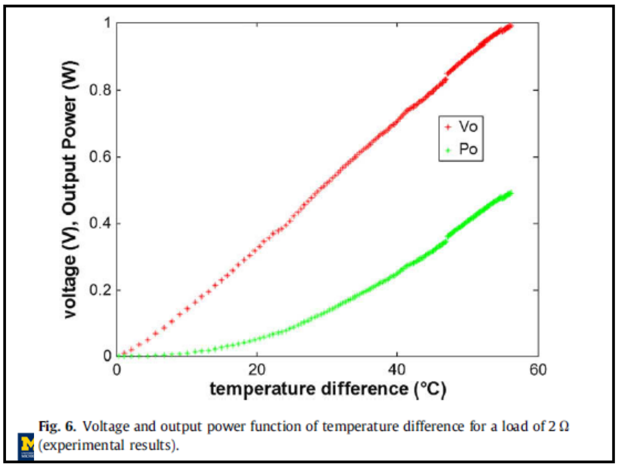

Fig. 6. Voltage and output power function of temperature difference for a load of 2 Ω (experimental results).

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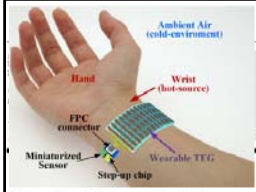

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Wearable thermoelectric generator to harvest body heat for powering a miniaturized accelerometer

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HIGHLIGHTS

- A novel structural design of the wearable TEG to harvest body heat is developed.
- The TEG features excellent flexibility and high power generation for body heat harvesting.
- A miniaturized accelerometer is powered by the TEG to detect body motion through harvesting wrist heat.

Efficiency of TE power generation

$$\eta_{max} = \frac{T_h - T_c}{T_h} \frac{\sqrt{1+ZT_{avg}} - 1}{\sqrt{1+ZT_{avg}} + \frac{T_c}{T_h}}$$

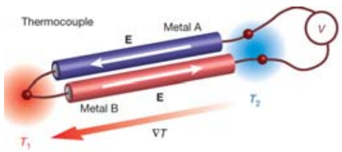
- *Figure of merit Z for TE material.*

  $Z = S^2\sigma/k$ where S, σ , k are the Seebeck coefficient, electrical conductivity, thermal conductivity, respectively.

Question:
Calculate the maximum efficiency for an ideal TE material, *ZT_{avg}=1, T_h=250C; T_c=20C*

Measuring Temperature

Thermocouple



K Uchida *et al. Nature* **455**, 778-781 (2008) doi:10.1038/nature07321

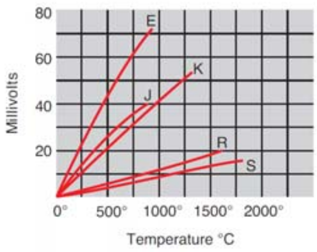
Voltage = f (ΔT, **TC material**)

- Cold Junctions: A known ref temperature

Thermocouple

Characteristics of standard thermocouples

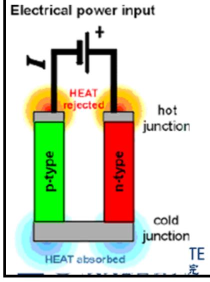
- Applications
- Cost
- Accuracy



Type	Metals + –
E	Chromel vs. Constantan
J	Iron vs. Constantan
K	Chromel vs. Alumel
R	Platinum vs. Platinum 13% Rhodium
S	Platinum vs. Platinum 10% Rhodium
T	Copper vs. Constantan

The Peltier Effect

- In 1834, a French watchmaker and part time physicist named Jean Peltier described thermal effects at the junctions of dissimilar conductors when an electrical current flows between the materials.



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Introduction to Heat Transfer

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Introduction to Conduction

Direct transfer of energy via

(i) lattice **vibration**s
(ii) electron movement
(iii) molecular collision

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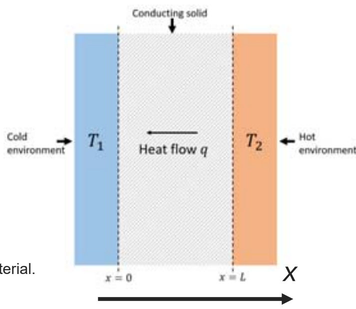
Thermal Conductivity

Fourier's law

- An observation for many materials.

q= $-k\,(T_2 - T_1)/L$

k: thermal conductivity,
a physical property of the material.



Question: What is the unit of k?

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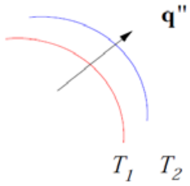
Fourier's law

$$q'' = -k\frac{\partial T}{\partial s}$$
$$\mathbf{q}'' = -k\nabla T$$



- proportional to the local gradient of temperature
- a vectorial quantity, which points in the direction opposite the temperature gradient, i.e. heat goes from hot to cold.
- heat flux lines are perpendicular to *isotherms*.

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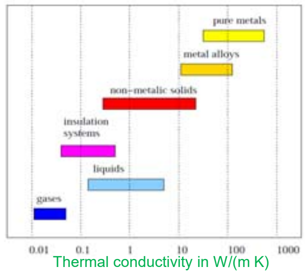
Thermal Conductivity



- Pure substances (gold, synthetic diamond carbon) have the highest conductivities, highly desirable for heat sink applications in computing. High conductivities are associated with regular lattices with little structural defects.
- Insulating materials are typically amorphous, such as glasses and ceramics.
- The thermal conductivity of solids and liquids can either increase or decrease with temperature.

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Thermal Diffusivity

$$\alpha = \frac{k}{\rho c}$$

- K thermal conductivity (W/(m·K))
- C specific heat (J/(kg·K))
- ρ density (kg/m³)

- Thermal diffusivity is the measure of thermal inertia.
- What does high thermal diffusivity mean?

Heat moves rapidly through it because the substance conducts heat quickly relative to its volumetric heat capacity or 'thermal bulk'.

Copper at 25 °C	1.11 × 10−4
Iron	2.3 × 10−5
Glass, window	3.4 × 10−7
Wood (Yellow Pine)	8.2 × 10−8

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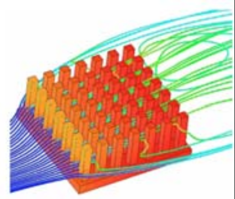
Extended Surfaces

- "Fins" create additional heat transfer area in a compact volume to enhance heat transfer.



Fins are used in:
- computer heat sinks, engine radiators, home heaters, heat exchangers, etc.

- The price to be paid?

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Our core project

- How's your design going?
  Get it going and improve ver 2.0
- Any "spare tire plan" ?
- Teamwork !
- Understanding !
- A "team log book"

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Some Safety Rules (Again!)

- Absolutely NO out-of-lab testing (playing with alcohol burner lamp outside of the lab is forbidden and will lead to failure of this course)
- The lab supervisor/manager, technicians, and teaching assistants will ensure that you know of specific hazards and use personal protection equipment (PPE).
- Read and obey all operational signs and warnings.
- Power must be switched off whenever an experiment or project is being assembled or disassembled.
- Make measurements in live circuits with well-insulated probes and one hand behind your back. Do not allow any part of your body to contact any part of the circuit or equipment connected to the circuit.
- Never handle wet, damp or ungrounded electrical equipment.
- Avoid contact with the hot components.
- Never short-circuit a power source.
- When using a voltmeter or ammeter, begin with the highest range and work your way down to a suitable range.

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Review

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