I Want My Pizza Hot!

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The Story Behind a New Product

It all started around the dinner table on a nice evening about mid May. The Smiths were having their dinner when Becky, the devoted mother, said to her husband, "Bob, honey, our kids worked hard and did great in school this year. They really deserve a special treat!" Bob agreed and turned to his children, Sarah and Dana, and asked, "What do you like?"

Sarah, the oldest, promptly replied, "Let's go camping!"

"What a great idea!" Bob exclaimed. "How about going to the Fall Creek Falls State Park?" he added.

Dana chimed in, "Yeah! We can go hiking, fishing, and enjoy the beautiful scenery!"

Suddenly, Bob got an inspired look on his face and said, "I will also prepare my special barbecue sauce and cook a nice dinner for you on the grill!"

The children groaned, "No, please daddy!" begged Sarah. "I don't want to eat any more of that burned stuff!"

Dana looked at Bob with pleading eyes and said, "Daddy, you know how much we love you, but you are the worst cook."

Bob laughed and said, "Okay, What do you want to have for dinner then?" Sam, the three year old finicky eater, toddled into the room and as usual, said "I want pizza!"

Sarah and Dana agreed instantly and said, "Yeah! Pizza!"

For once, Becky didn't put up a fight, "Good idea, now I can really enjoy my vacation!"

Bob turned to his family and said, "The Park is at least an hour away from the nearest pizza place and I know you won't eat a cold pizza."

"You're the engineer Bob," reminded Becky, "Aren't you supposed to solve problems rather than create them?"

At that time, a light bulb was blinking inside Bob's head. Bob was an electrical engineer working for the Electrical Products Division of Heatcraft in Murfreesboro, Tennessee. His company, a premier supplier of electronic controls and electric heating products worldwide, had just developed a new flexible polymer heater named Polytherm™. Bob's fellow engineers predicted a wide range of residential and commercial uses and were exploring such applications. Bob smiled and turned to his family and said, "I think we can use Polytherm™ to keep the pizza hot during our drive to Fall Creek Falls."

"What's a holly germ dad?" asked Sam.

"He didn't say holly germ," said Sarah. "He said rolly worm."

Bob laughed and said, "No, no, I said Polytherm™! It is a new material that our company developed which is flexible, strong, and works kind of like an electric blanket."

Knowing that his conversation with his children was going to be fruitless beyond that point, Bob promised to work on a portable pizza warmer at his company for his family's camping trip.

Objectives

With the successful completion of this case, the participant should be able to:

- Model an electrical circuit based on a real electrical load.
- Use critical thinking and apply basic algebra in problem solving.
- Convert between systems of units.
- Calculate the resistance of a material from its physical parameters.
- Apply Ohm's law in DC circuit analysis.
- Calculate power and energy.
- Conceptualize duty cycle and basic heat transfer.
- Consider electrical safety measures.
- Use spreadsheets, interpret data, and apply charting skills.
- Use software to simulate electrical circuits.
- Use oral and written communications skills to present data and conclusions.

The Birth of a Design Idea

At night, Bob tossed and turned in bed trying to find a good solution for his family's little project. He knew that he had to define the initial design requirements of the pizza warmer. "How? From where? What will it cost?" Several questions came to his mind as he was trying to sleep.

Q.1. Please help Bob get his badly needed sleep by listing, what you consider, the essential design requirements of the portable pizza warmer.

The next morning, Bob could not wait any longer. He just knew that other families as well as businesses could use the pizza warmer he was creating for his family trip. He rushed to his company and called his technical group together for an emergency meeting. He shared his vision with the group and asked for their help. They all recognized the commercial applications of Bob's idea and the benefits to their company.

The Design Process

The group started the design process by examining the electrical and mechanical characteristics of Polytherm™.

Bob said to his fellow engineers, "As you know, the material comes in sheets of different widths ranging from 6 to 40 mils in thickness that are lightweight, flexible, and yet rugged."

Tom, the newest member in the group, interrupted Bob and said, "That is amazing! Polytherm™ sheets are only 6 to 40 thousandths of an inch thick."

Bob replied, "You're correct." He then added, "The material consists of a flexible conductive polymer material with integral copper bus wires, and can be manufactured to fit shapes, wrapped to fit specific heating contours, and can accommodate notches, cutouts and holes without compromising heater performance. Polytherm™ can operate on voltages as low as 12 V and as high as 600 V. Its resistivity is found to be 0.035 Ohm at room temperature and is almost constant over the temperature range of our interest. It can also operate safely at different temperatures ranging from minus 100 to plus 200 degrees centigrade." Bob handed out a colored brochure to his team members and said, "Our Marketing Department actually just finished producing this brochure that includes a photo of Polytherm™ sheets as well as some specifications and possible applications."

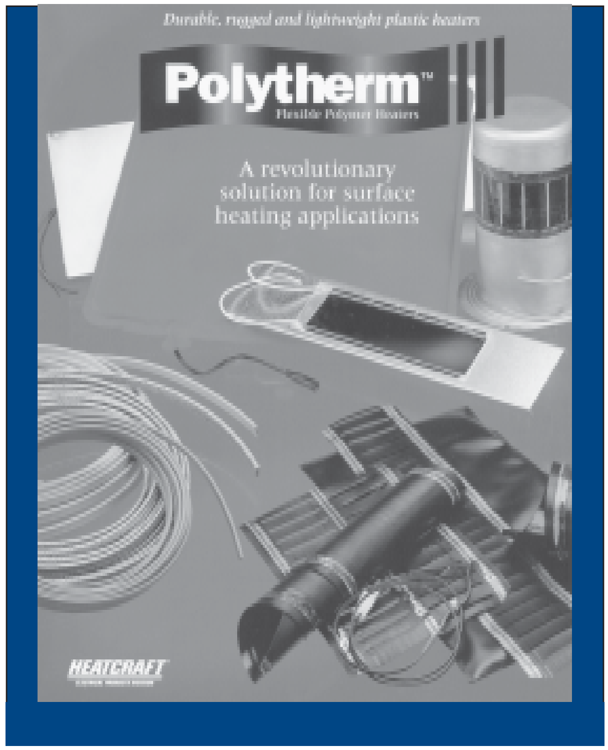
> **Q. 2.** What are the advantages of Polytherm™ over a traditional heating wire?

The team discussed the initial requirements that Bob had laid out when he was designing the pizza warmer for his family's trip and finalized the design criteria. The team agreed on using a 13-mil thick sheet and came up with the design shown in Figure 1 (a&b). For safety measures, the team integrated a fast-blow fuse into the warmer's plug to protect against overcurrent. In addition, two bimetal snap-action thermostats with an 85° C set point were used in series in order to regulate the temperature (the fuse and thermostat resistances may be ignored when both thermostats are ON).

> **Q. 3.** In your opinion, why were there slits made in the Polytherm™ pizza warmer? Would more slits produce more heat? Explain.
>
> **Q. 4.** Why do you think the team used two thermostats? Is the location of these thermostats important? Explain.

Bob asked Tom, "What do you think the thermostat's duty cycle should be under normal operating condition?" Tom replied, "Oh, you mean the ON time versus the ON and OFF time." He then added, "I am sure the ambient temperature and the insulation materials play a major factor here."

Bob smiled and said, "That is correct, we can address these issues as well as others experimentally later on. Let's now get to work and examine that sucker!" While the other team members discussed cost factors, manufacturing, production, and marketing issues, Bob and Tom were trying to analyze the Polytherm™ heating element.



> **Q. 5.** How do you think the warmer's insulating materials and ambient temperature affect the duty cycle? Would the duty cycle in a colder climate be greater or smaller than that of a warmer climate? Explain.

Bob asked Tom, "What should we do? Where do you want to start?"
Tom replied, "I am really good in circuit analysis and I can take care of this on my own." He continued as he grabbed his notebook and calculator, "I will get back with you in few minutes."

Sure enough, Tom sat behind his desk and started writing in his notebook the following:

Pizza Warmer Project

Today's Date

Time

• Find the resistance between two adjacent copper buses. "I have all needed parameters, that shouldn't be a sweat. For simplicity, I will assume that slits are rectangular in shape."

• Find the total resistance as seen at the two terminal leads of the warmer. "Well, adding resistors in series and parallel gets me really excited!"

• Find the total current when the warmer is ON. "I will assume that the voltage from the car's battery is 12 V."

• Find the power dissipated. "Since electrical power will be converted to heat, this will give me a good idea in comparison with other electrical devices such as a light bulb."

• Find the heat produced in the warmer over a period of one hour. "I will assume that the thermostats duty cycle is 50%."

Figure 1. a. Polytherm™ Pizza Warmer with an Optional 120V Adapter

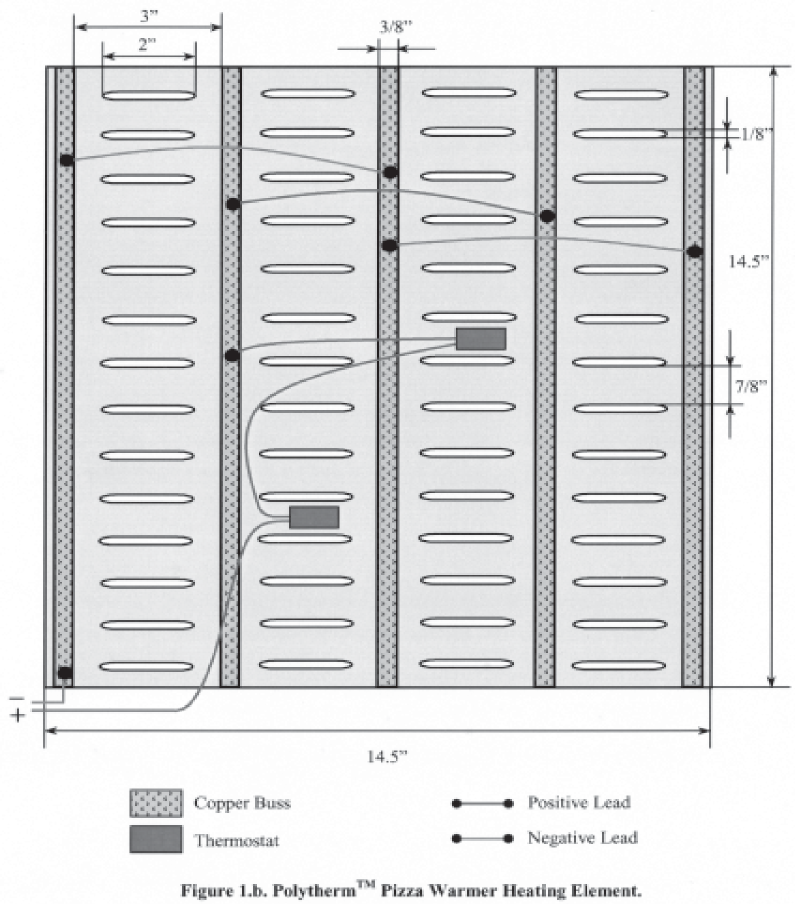


Figure 1. b. Polytherm™ Pizza Warmer Heating Element

Q. 6-10. Pretend that you are Tom. Can you follow his steps described above and find what he is looking for? How should you present your findings to Bob? Would a "scratch paper" type report be OK? Explain.

Thirty minutes later, Tom hurried to see Bob in his office. "Knock knock ... I got it". Hearing Tom's voice, Bob looked up from behind his computer and said, "That was fast. Let me see here. Oh, this looks very professional, I am impressed".
Bob examined the data and asked Tom, "Did you also plot the VI curve?"
"Not yet," Tom replied. Bob continued, "Let's assume that the applied voltage changes from 0 to 15 V in a one Volt increment, we can then find the total current in each step and plot it versus voltage to get the VI characteristic curve."
Tom replied, "I can do that very fast using either spreadsheet, simulation software, or even by writing a short computer program. I will be back in minutes".

Q. 11. Use one of the above methods to plot the VI curve of the pizza warmer.

Q. 12. What will happen if one of the jumper wires is disconnected?

Additional Questions

Your instructor may assign additional questions here.

Q. 13. Pretend that you are Bob. Explain how the warmer works to your children in a way that they can understand.

Q. 14. Make a list of other possible uses for this technology.

Q. 15. Research the patent process. Pretend that you are Bob and apply for a patent for your new pizza warmer invention.

Q. 16. Now that your instructor has assigned each of you to a team, develop a team presentation for one alternative use of this technology and "sell" your new product to your classmates in an oral team presentation.

Q. 17. Pretend that you are Bob and design a presentation to sell the pizza warmer to a business. What type of businesses would be interested in this invention? What differences will you have to consider when preparing your presentation to these different companies?

Instructor's Guide

Case Synopsis

This case can be used to illustrate the modeling of a real electrical load into a circuit representation. It also can be used to demonstrate the applications of basic physical laws in DC circuit analysis for calculating resistance, current, power, and energy dissipation as well as the concepts of duty cycle, heat transfer, and electrical safety measures. The case highlights the use of spreadsheets, charting skills, and using software to simulate electrical circuits. It is structured to emphasize critical thinking, team approach, active collaborative learning, and the use of oral and written communications. The case is intended for an introductory course in DC circuit analysis.

This case deals with the pizza warmer that Heatcraft-Electrical Product Division in Murfreesboro, Tennessee is producing and marketing. The company is a premier supplier of electric heating products worldwide. In early 1999, Heatcraft developed a new polymer heater and named it Polytherm™. This revolutionary material can operate in a wide range of voltages and comes in the form of thin flexible sheets with integral copper bus wires. Polytherm™ can be manufactured to fit shapes, wrapped to fit specific heating contours, and accommodates notches, cutouts and holes without compromising heater performance.

One of the applications of Polytherm™ that Heatcraft has successfully marketed is the pizza warmer oven that is currently being used by a major pizza company. One or two Polytherm™ heater pads are used in each oven, depending on the oven size. The warmer operates on 12 V and can be used to keep the pizza warm in stores (with an AC adaptor) for take-out orders or plugged into the cigarette lighter outlet of most cars for delivery orders.

Several design and safety considerations are examined and the electrical modeling of the heater pad is discussed. The Polytherm™ material has several advantages over a traditional heating wire, particularly in this case. Furthermore, Heatcraft is currently developing a wide range of marketable applications.

This case represents the final product that Heatcraft had extensively developed, tested, and successfully marketed. All specifications given here are true and provided by the engineering team that has developed the pizza warmer. The story behind the invention is fictional and serves as a "hook" to the reader.

Target Student Audience

This case is intended for use in an introductory course in DC circuit analysis.

Prerequisite Knowledge

Prior to applying this case, the student should be exposed to the principles of calculating the resistance of a material from its resistivity and geometry, the concept of adding resistors in series and parallel, and the methods of calculating electrical power and energy.

Suggested Teaching Technique

Although this case can be assigned to students on individual basis, it is highly recommended that collaborative learning be used here. The problem may seem very simple at the first look; however, it actually requires a considerable amount of critical thinking and problem solving skills. The team approach usually generates more self-confidence and excitement in solving such a problem. Students may be arranged in groups, each consisting of three to four students with a team leader and a secretary or a reporter with rotated responsibilities between teammates. Each group is given one instruction set and asked to present their findings in oral and written reports. The instructor should be able to ask any member of the group to present the oral report to the whole class.

Case Sequence

Session I

In order to encourage critical thinking and participation, students are asked to read the first part of the case and discuss with their teammates possible answers to questions 1 through 5. The instructor then selects a student from each team to present one answer at a time to the whole class until all possible answers are exhausted. The instructor may also give hints to students if a particular answer is not mentioned (e.g. what about the power source?). Some of these questions can be assigned also as individual or team homework. Grades may be assigned to these activities as the instructor sees fit.

Possible answers to Q. 1:

1. The pizza warmer should get its power from the cigarette lighter of the family's car.
2. It should keep the pizza warm but not overheated.
3. It should be self-regulating with a preset temperature.
4. It should not draw a large current nor be a burden on the electrical system of the car.
5. It should incorporate appropriate safety measures.
6. It should be simple to connect and operate.
7. The heating element and the pizza should be placed in a well-insulated "bag" to minimize heat loss.
8. It should be portable and affordable.

Possible answers to Q. 2:

1. Heat is produced by the whole surface as opposed to a concentrated thin wire area.
2. If the heating wire is damaged, the warmer will cease to function. On the other hand, if a part of the Polytherm™ is damaged, the remaining area may still produce heat.

Q. 2

3. Polytherm™ is durable, rugged, flexible and lightweight.
4. Simpler temperature regulation.
5. It can be cut to size and fit to shape.
6. It is safer because heat is not localized in a small area such as the case of a heating wire.
7. It can operate in a wide range of temperatures and voltages.

Possible answers to Q. 3:

1. Slits are used to control the resistance of each section of the warmer so that the resulting total resistance dissipates a predetermined amount of power or heat.
2. The heating element becomes more flexible. Of course, the Polytherm™ element can be made thinner without using slits; however, it may become less durable.
3. Air circulation and heat transfer are enhanced using slits so that hot air is not trapped.
4. For the same thickness, more slits re sult in a higher resistance, producing less heat ($P = V^2/R$).

Possible answers to Q. 4:

1. Two thermostats improve safety and temperature measurement and control.
2. They are located in the two middle sections of the warmer and are placed on opposite sides of the center to give better temperature indication.
3. It is expected that the center section of the warmer will have more concentrated heat.

Possible answers to Q. 5:

1. The better insulation the pizza bag material has, the smaller the duty cycle is (the warmer is ON during shorter periods of time).
2. In a warmer climate, the temperature gradient between the inside and out side the pizza bag is less, resulting in lower heat loss and a smaller duty cycle.

Session II

After students have the chance to discuss the problem in teams outside the class, the following steps can be considered:

- Class discussion on modeling electrical circuits and how to model the Polytherm™ element into an equivalent circuit.
- A simple equivalent connection diagram representing the heating element of Fig. 1.b. should be drawn. Current flow through each section of the warmer should be explained through in-class team approach using hand-drawn sketches and oral presentations. After group discussions, the entire class should adopt a common diagram similar to the one shown in Figure 2.
- Team discussion, written report, and/or oral presentation on how to proceedshould be carried out from Figure 2 to an equivalent electrical circuit. Discussion of resistance, current flow, and parallel/series circuits should be included. The components of each of the four sections as well as the physical dimensions should be identified via class discussion.

Homework (or Session 2 continues)

- Unit conversion for resistivity from Ω•m to Ω•in should be explained.
- The resistance in each section, the equivalent electrical circuit, and the total resistance should be identified.
- Individual or team written assign ments:
  a. The total current should be calculated.
  b. The total power should be calculated.
  c. The total energy dissipated per hour should be calculated.
  d. The voltage should be varied from 0 to 15 Volts and the current and power should be plotted versus voltage with some explanation. (Optional)

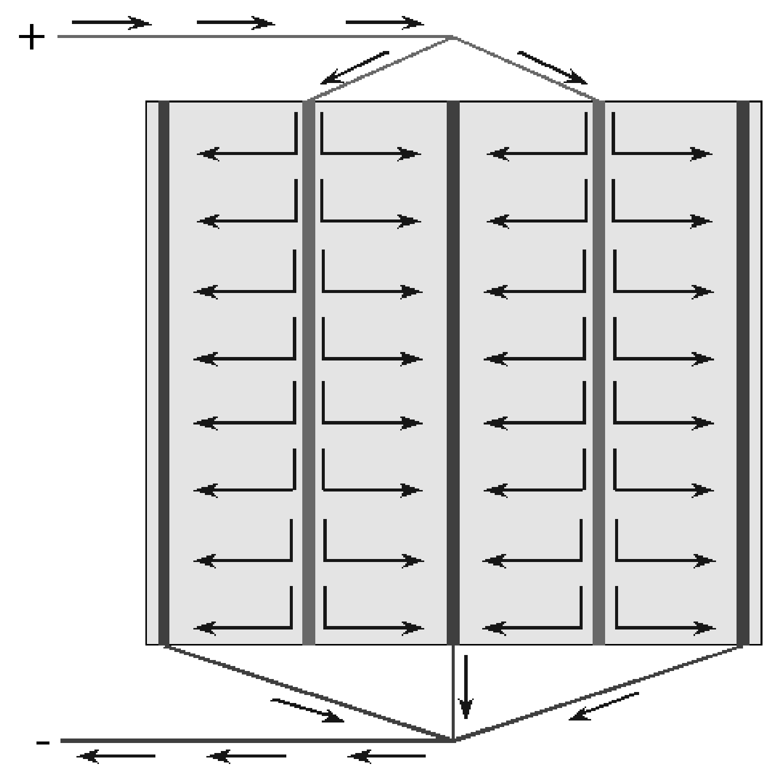


Figure 2. Equivalent Connection Diagram of the Pizza Warmer.

Session III

The activities listed below are optional and may be performed in class or assigned as homework.

- Critical thinking—Group discussions (brainstorming) on safety and liability issues possibly involving:
  a. Number of thermostats
  b. Location of thermostats
  c. Warning labels
  d. The use of current limiting devices
  e. Physical abuse or damage
  f. Protective and insulation covering
  g. Overvoltage protection
  h. Why use Polytherm™ (Hint: compare to a conventional heating pad/ blanket).
- Each team presents its findings to the whole class.

Session IV

The activities listed below are optional and may be performed in class or assigned as homework.

- Critical thinking—Discuss these design issues as individual written home work:
  a. Why the use of slits? (Slits increase resistance resulting in lower power).
  b. What is the significance of slit size?
  c. What is the significance of number of slits?
  d. What is the significance of the warmer's physical dimensions, i.e., length, width, and thickness?
  e. What is the significance of the warmer's shape?
- The above questions can be answered by using spreadsheets or computer programming if available.
- Individual written report on alternative uses.

Solution

1. The heating element can be redrawn as shown in Figure 2 on the previous page.
2. The five-copper buses (strips) and the corresponding areas of Polytherm™ material create four parallel branch resistances. If there were no slits in the material, the equivalent circuit may be constructed as shown in Figure 3a. The effect of the slits can be seen, however, as a series resistor, R2, in each branch in addition to the two resistors of the two sides as shown in Figure 3b.
3. To simplify calculation, the three resistors in series can be viewed as two resistors in series. One represents the central section that has slits, R2, and one represents the sections that do not have slits, R1 + R3, as shown in Figure 3c. At this point, the use of some animation by having a sheet of paper cut in a shape similar to one branch will help. The center section should be cut and squeezed in the middle and the two side portions should be combined into one as shown in Figure 3.

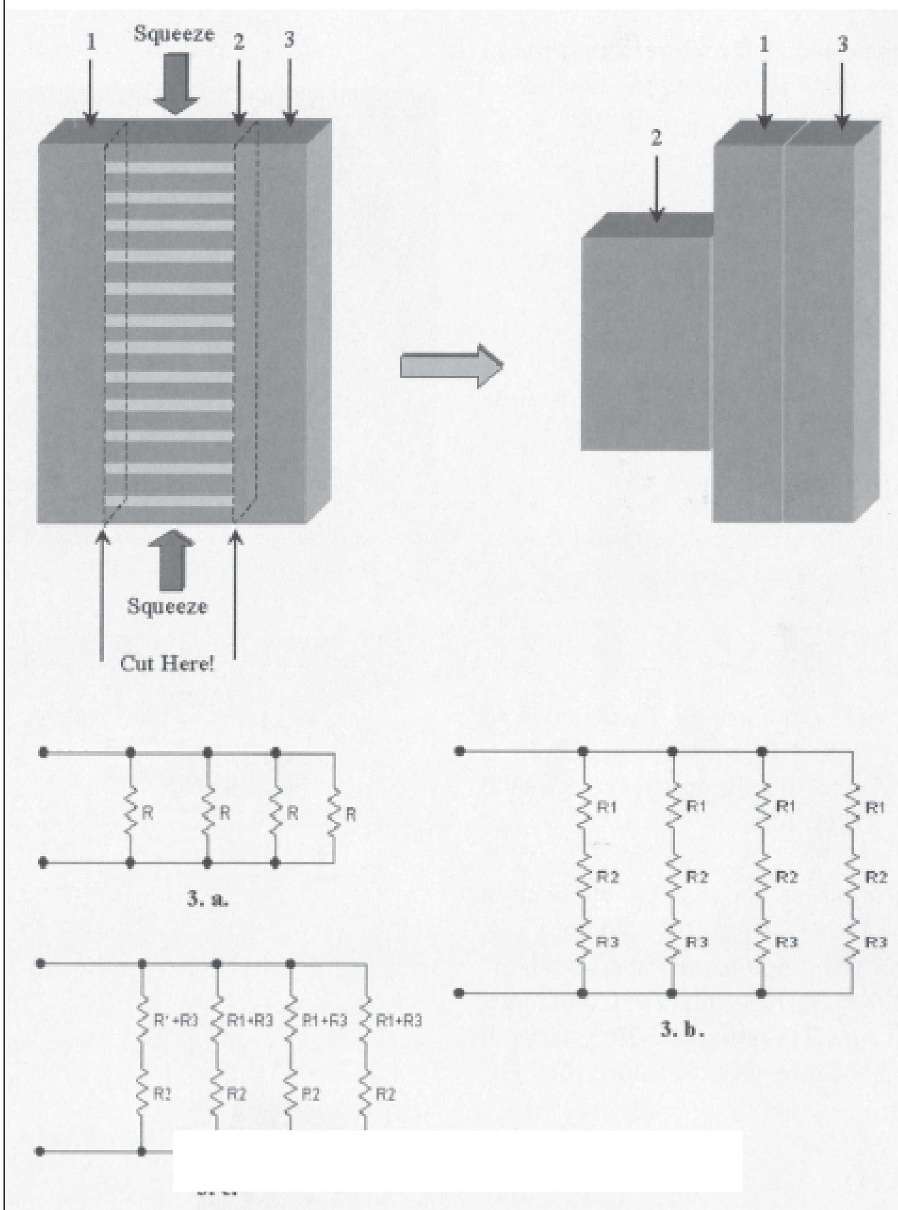


Figure 3. Pizza Warmer Equivalent Electrical Circuit.

4. The resistance of each section between two adjacent buses can be found by calculating the value of each of the two series resistances using the following formula:

$$R = \rho\, l / A$$

Where: ρ is the resistivity in Ω•m
l is the length in meter.
A is the cross sectional area in m^2.

5. The resistivity should be converted from Ω•m to Ω•in:
$\rho = 0.035$ Ω•m x 39.37 in/m = 1.378 Ω•in

6. The resistance of each section is found to be about 24 Ω, making the total resistance of the heating element 24/4 = 6Ω as shown below:

$$R_1 + R_3 = 1.378 \times \frac{(3\text{-}2)in}{(14.5in \times 0.013in)} = 7.31\Omega$$

$$R_2 = 1.378 \times \frac{(2)in}{[(14.5\text{-}14 \times 1/8)in \times 0.013in]} = 16.63\Omega$$

7. The total current can be found from:
I = 12/6 = 2 A.

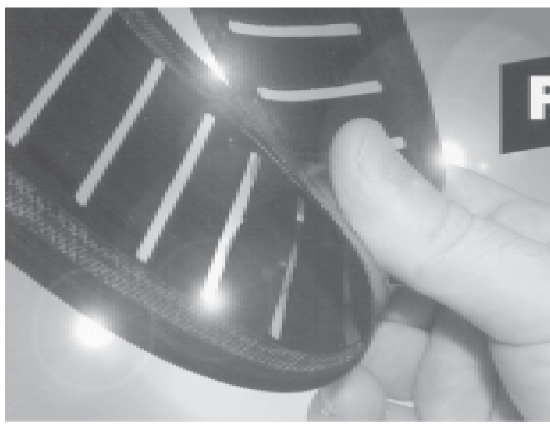
8. Then the power, P = 12 x 2 = 24 W.

9. The maximum energy dissipated in an hour is 3600 x 24 = 86400 Joules. For a duty cycle of 50% the energy is 0.5 x 3600 x 24 = 43200 Joules.

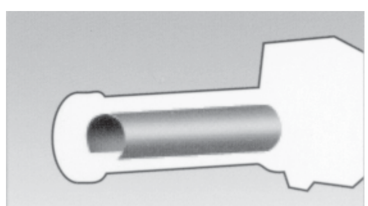
10. Information about patent application can be found at http://www.uspto.gov. Several publications are also available from the U.S. Department of Commerce, Patent and Trademark Office, Crystal Park 3 - Suite 441, Washington, DC 20231.

Additional Problems

This case can be used to present or discuss simple concepts of heat transfer and thermodynamics. The following questions can be presented to the class/teams for group discussion and homework.
1. How do you convert the energy found to Calories or BTUs?
2. How do you relate the energy dissipated to the surface temperature of the insulating container (bag) that surrounds the Polytherm™ unit and the pizza? Possible applications of the Polytherm™ material are shown below.



Polytherm™ is a unique conductive polymer material that is flexible and lightweight. Operating voltages as low as 12 Volts and as high as 600 Volts make it a viable, cost effective heating solution for a wide range of applications.



Closeup of hand grip

Outdoor recreational and industrial equipment can be made more safe and comfortable with cost-effective Polytherm™ heaters. The heater can be easily shaped and applied to hand grip profiles, and is so thin that it does not hinder performance or compromise physical comfort.

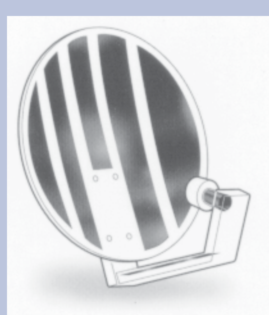
Polytherm™ heaters are ideal for vehicle seats because Polytherm™ is flexible, inexpensive and can be cut and shaped to any configuration.

Compressor heaters that need to be wrapped around curved surfaces are an ideal Polytherm™ solution.

WinterWrap Heating Cable is made with Polytherm™.

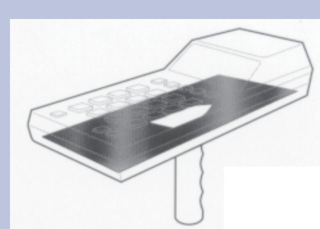
In commercial and institutional food service environments, Polytherm provides a rugged, yet safe and lightweight method of heated food staging and holding.

Heated thermal bags for Home Meal Replacement (HMR) and restaurant take-out are heated with Polytherm™ heaters. These lightweight, low voltage heaters can be easily powered from the automobile cigarette lighter, making them the perfect portable heated transportation solution for hot food.



The flexible polymer heater Polytherm™ keeps snow and ice from accumulation on satellite dishes and antennas.

Temperature sensitive circuits and small electronic devices can be kept at exact operating temperatures with Polytherm™ heaters.



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