7. Fire Spread Processes: Cutting Edge Research on Heat Transfer, Fuel Properties, Pyrolysis, and Ignition

Lesson Overview: This culminating lesson on the physical science of wildland fire challenges students to expand their understanding and link their knowledge of heat transfer processes, fuel properties, pyrolysis, and ignition through a series of thought-provoking videos and a presentation about current research – in particular, research currently underway at the Missoula Fire Sciences Laboratory on heat transfer and ignition.

Subjects: Science, Reading, Writing, Speaking and Listening, Arts
Duration: 40 minutes
Group size: Whole class
Setting: Indoors
No new FireWorks vocabulary

Lesson Goal: Students learn about current fire spread research and expand their understanding of basic fire spread processes.

Objectives:

- Students will use their understanding of radiation and convection to explain how wildland fuels of different sizes and shapes are heated to ignition in different ways.

Standards:		9th	10th	11th	12th
CCSS--ELA	Writing Standards	1,4,7,10		1,4,7,10	
	Speaking and Listening	1,4		1,4	
	Science/Technical Subjects	7,10		7,10	
NGSS	Energy	PS3.A, PS3.B, PS3.D			
EEEGL	Strand 1	A,B,C,D,E,F,G			

Teacher Background: Early research on fire behavior modeling (1960s-1970s) focused on predicting the rate of spread of wildland fires rather than understanding basic fire spread processes. It was assumed that rate of spread was controlled by heating through radiation, although this assumption was not tested experimentally at the time. The resulting fire spread models, which fire managers still use to predict the spread on wildland fires, are based on the assumption that radiation drives fire spread.

To better understand how wildland fires spread, current research is focusing on the physics of fire spread. Recent observations on wildland fires and on highly controlled laboratory fires, including many experiments conducted by Dr. Sara McAllister and Dr. Jack Cohen at the Missoula Fire Sciences Laboratory, have caused scientists to question the general assumption that radiation governs fire spread. They are now investigating flow dynamics at the flaming front, the conditions needed to sustain ignition in fuels of different sizes and shapes, the ways in which flames are propagated through fuels, and the ways in which fire burns in live fuels.

This activity focuses on just one aspect of current research: understanding how individual fuel particles are heated to the ignition point. This is important because it determines when the particle will ignite and how long it will continue to burn. The activity asks students to draw on their knowledge of heat transfer, fuel properties, and pyrolysis. With this knowledge, they learn that cutting-edge research sees fire spread as the result of a sequence of ignitions, and that particles are heated to ignition in different ways: Fine fuels are heated mainly by convection and coarse particles mainly by radiation.

Materials and Preparation:

- Download *H07_HeatTransfer_FuelProperties.pptx.* Check that the video segments work.
- Make 1 copy of ***Handout H07-1*** per student.

Procedure:

1. Begin the PowerPoint presentation. Show only slides 1 and 2.
    - Slide 1 reviews heat transfer processes (conduction, radiation, and convection).
    - Slide 2 reviews the fuel characteristics of fine and coarse fuels.

2. Pass out the handout. Have students answer question 1.

3. Return to the PowerPoint. View slide 3, a video recording of a crown fire spreading through a forest. Ask students to watch for anything that surprises them. Pause the Powerpoint. Have students answer question 2 on the handout.

4. Very observant students may have been surprised to see that the large, horizontal log in the foreground ignites before the fine surface fuels near it. If no one mentioned this, point it out. Return to the PowerPoint, slide 4, in which you view the same video at half speed. Pause and discuss preconceptions (that fine fuels always drive fire spread) and what the video shows (ignition of a large log ahead of fine fuels). Is anyone surprised? Even if the students weren't, tell them that scientists studying fire behavior were puzzled with this observation!

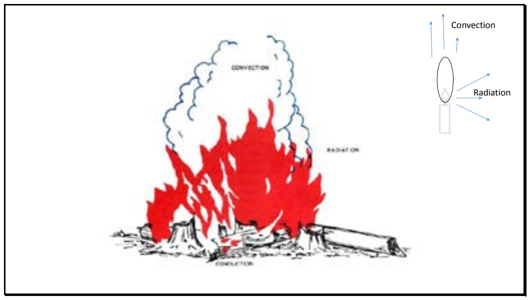
5. Continue the PowerPoint presentation to learn about the complicated relationship between heat transfer processes and fuel particle size and shape.

Assessment: Have students complete the rest of Handout H07-1.

Evaluation: Refer to the Handout H07-1 answer key.

Slides and Narrative for *H07_HeatTransfer_FuelProperties.pptx*

Slide 1



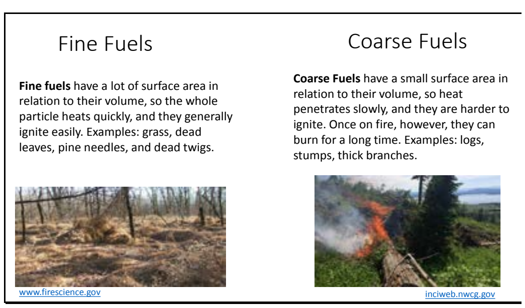
Review:

Conduction: Heat is transferred through the direct contact of atoms or molecules within solid objects. In wildland fire, conduction enables heat to move from an object’s outside to its inside and from one solid object to another one that it is touching.

Radiation: Heat is transferred through space. Heat from a fire travels as waves or particles through the space between air molecules and heats the first molecules it touches, such as wildland fuels.

Convection: Heat is transferred as hot gases (or liquids) expand and move from a hot area into a cooler area. In gases, convection is the expansion of a bubble of hot gases into the cooler gases surrounding it. Since Earth’s atmosphere becomes “thinner” (less dense) as you go up in altitude, “up” has less resistance to the expanding gases than “sideways” or “down.” Thus hot air generally rises, as do the hot gases produced by fire.

Slide 2



Remind students what they learned in the fuel properties lesson: that fuels with higher surface area to volume ratio (SA/V) have more surface available to absorb heat than fuels with a lower SA/V. Thus one may expect that fine fuels, which have a high SA/V, should gain heat faster and ignite more quickly than coarser fuels, which have a low SA/V.

Slide 3

Show this video, which is played at actual speed.
Pause the presentations so students can answer Question 2 on the handout.

Slide 4

Show the same video played at half speed. Focus on the big log at the center of the video. What ignites first? After a class discussion and watching this video, students may wish to change their answers to Question 2.

Slide 5

This is surprising! We thought that fine fuels were easier to ignite than coarse fuels….

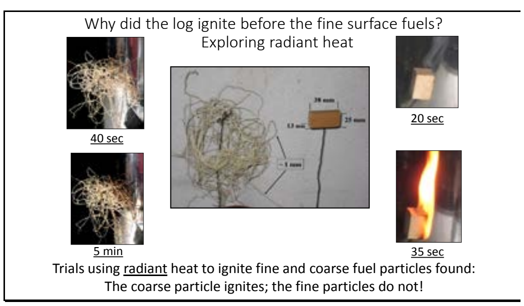
So why is it easier to light campfires when we put fine fuels on the bottom and coarse fuels on top?

The relationship among heat transfer processes (radiation vs. convection), fuel size, and fuel shape matters.

Let's take a closer look at this!

Did the video meet our expectations about ignition of fine vs. coarse fuels?

Slide 6

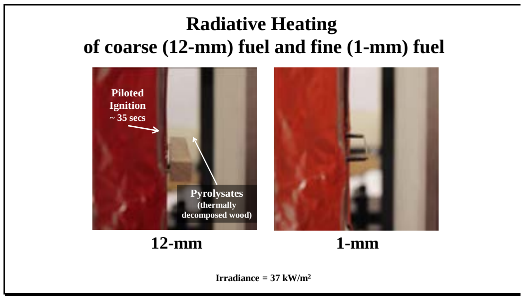


Scientists at the Missoula Fire Sciences Laboratory in Missoula, MT, tested fuel particle heating and ignition of fine and coarse fuels using <u>radiant heat.</u> (FYI: 37 kW/m^2 Irradiance.)

- Scientists put fine and coarse fuel particles at the same distance away from a radiant heater and timed how long it took to ignite the fuels.
- They found that the coarse wood block began to pyrolize after 20 seconds and ignited at 35 seconds, while the fine fuels did not ignite at all.

- This is surprising given the assumption that fine fuels should ignite more quickly than coarse fuels. However, it confirms what we observed in the video, that coarse fuels may ignite more quickly than fine fuels.

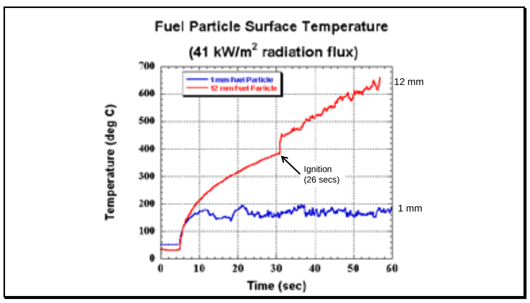
Slide 7



Here is another demonstration of radiant heat, showing that coarse fuel may ignite more quickly than fine fuel. Watch the two videos (both images are videos).

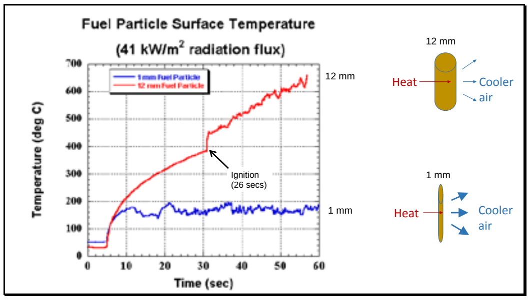
In these videos, you can see the coarse wood begin to pyrolyze at about 10 seconds. The fine wood particle does not pyrolyze at all and therefore would not ignite because it did not get hot enough to produce flammable gases.

Slide 8



Another trial.
This time scientists measured the surface temperature of coarse and fine fuel particles exposed to radiant heat.
We see that the temperature of the coarse fuel (12 mm- in red) rose quickly, and the particle was ignited at about 400 degrees C.
The temperature of the fine fuel (1 mm- in blue) did not rise above 200 C, the minimum temperature for pyrolysis, so combustion could not occur.

Slide 9



Why doesn’t the fine fuel heat up as quickly as the coarse fuel?

The sides of the fuel particles facing the heat source are heating up (heat is being transferred from the heat source to the fuel particles), and then the heat is conducted through the particle.

Because the coarse particle is so big, only a little heat makes it all the way through the particle. This means that there is not much heat on the backside of the coarse particle that can be transferred to the cooler air on the side away from the heat source.
Because the fine particle is so small, heat is easily conducted through it. This means that a lot of heat can be transferred from the back side of the fine fuel particle to the cooler air on the side away from the heat source.

Another reason that the fine particle does not heat up as quickly as the coarse particle is that air flows around the two particles differently because of their different sizes. Heat is lost is more efficiently around the fine particle than the coarse particle.

That is why cooling fins on refrigerators are thin. Can you think of other examples?

Slide 10

So…We see that radiant heat can heat coarse fuel particles and ignite them more quickly than fine fuels.

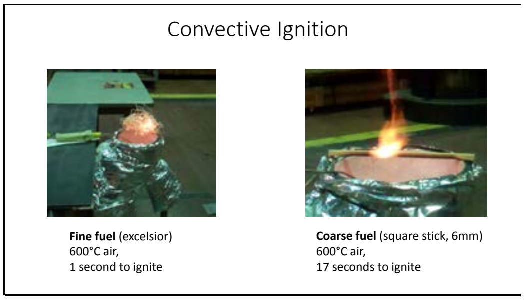
So what kind of heat **does** ignite most of the fine fuels? Why are they usually the fuels most important to fire spread?

Let’s look at convection.

If we examine fuel particle size and shape under convective heat instead of radiant heat, do we get the same results?

Current state of knowledge, based on Sara McAllister’s and Jack Cohen’s research at Missoula Fire Lab.
The relationship between heat transfer processes (radiation vs. convection) and fuel size and shape matters. (Conduction is not directly addressed in these experiments.)

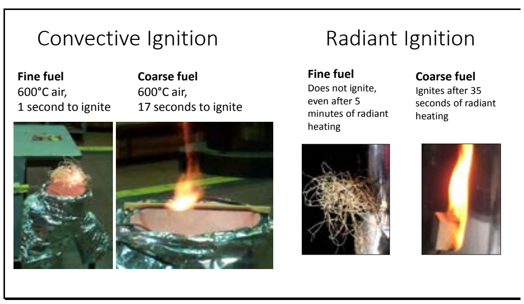
Slide 11



Scientists at the Missoula Fire Sciences Laboratory in Missoula, MT, tested heating and ignition of fine and coarse fuels using convective heat.

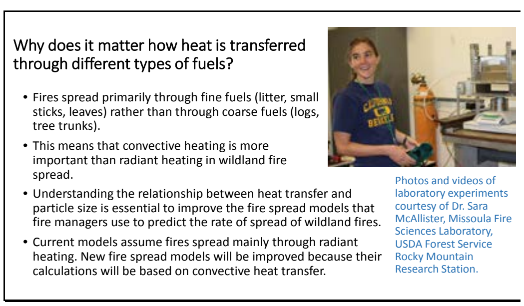
- They put fine and coarse fuel particles at the same distance above a hot air torch (works like a very powerful hair dryer) and timed how long it took to ignite the fuels.
- The fine fuels ignited at 1 second, while the coarse stick ignited in 17 seconds.
- This result is the opposite of what they found with radiant heat.

Slide 12



So we see that convective heat is more efficient at heating fine fuels (images on left), and radiant heat is more efficient at heating coarse fuels (images on right).
Why does this matter?

Slide 13



Handout H07-1: Heat transfer and fuel properties

Name ___________________________

View slides 1-2 of the presentation. Then answer this question.

1. This image shows a crown fire burning through a forest. The fire is moving from the left to the right. Predict which fuels will ignite first as the fire passes into the center of the image.

View slide 3 of the presentation. Then answer this question.

2. Was your prediction correct? Which fuels ignited first? If your prediction was not correct, are you surprised by what you observed?

After the presentation, answer these questions.

3. Describe and draw how you would build a campfire to ignite readily and then keep burning. Label your fine fuels and coarse fuels. Show where you would ignite the campfire.

4. Where is the heat from the match going? What kind of heat is igniting the fuels and what fuels do you expect to ignite first/last?

5. If you build a fire in a tepee shape, once the coarse fuels are burning, why does the teepee shape help to keep the coarse fuels (large sticks) burning?

6. What would happen to the burning large sticks if you knocked the tepee over and scattered the large sticks around your fire ring?

7. In the video, what kind of heat transfer caused the coarse log to ignite before the fine fuels around it?

8. What kind of heat usually causes fine fuels to ignite very quickly and usually be at the forefront of fire spread?

Handout H07-1 KEY: Heat transfer and fuel properties

Name ________________________________

View slides 1-2 of the presentation. Then answer this question.

1. This image shows a crown fire burning through a forest. The fire is moving from the left to the right. Predict which fuels will ignite first as the fire passes into the center of the image.
   Any answer is okay. This question is to get students thinking.

View slide 3 of the presentation. Then answer this question.

2. Was your prediction correct? Which fuels ignited first? If your prediction was not correct, are you surprised by what you observed?
   Student answers should reflect their answer to question 1.

After the presentation, answer these questions.

3. Describe and draw how you would build a campfire to ignite readily and then keep burning. Label your fine fuels and coarse fuels. Show where you would ignite the campfire.
   I would put the fine fuels on the bottom and coarse fuels on top. I would ignite the fine fuels from the bottom.

4. Where is the heat from the match going? What kind of heat is igniting the fuels and what fuels ignite first/last?

Convective heat from the match is rising, heating, and igniting the fine fuels. With enough heat, the coarse fuels above will ignite.

5. If you build a fire in a tepee shape, once the coarse fuels are burning, why does the teepee shape help to keep the coarse fuels (large sticks) burning?
When large sticks are burning and facing each other, heat, especially radiant heat, is trapped inside the tepee. This helps to sustain the burning.

6. What would happen to the burning large sticks if you knocked the tepee over and scattered the large sticks around your fire ring?
The large sticks would likely go out because the radiant heat is escaping, and there is no convective heat coming from the ground or radiating up around the fuels.

7. Based on what you have learned from the presentation, think again about the video that shows the coarse log igniting before the fine fuels around it. What kind of heat transfer probably caused the log to ignite before the fine fuels?
Radiant heat

8. What kind of heat usually causes fine fuels to ignite very quickly and usually be at the forefront of fire spread?
Convective heat.