All Fired Up — Forest Firefighter

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Application

You've probably seen or heard tales on the news about the heroics of forest firefighters as they battle and conquer raging infernos.

"Trying to battle Mother Nature is a thrill in itself," says Kole Berriochoa, who heads up one of the top firefighting crews in North America. "It's like you're always playing a chess game, trying to figure out the next move and counter it." Since the risk of death or injury is very real, there is no room for errors.

Forest firefighters work to control and put out wildland fires. They work in remote and often inaccessible parts of the country. They use heavy equipment such as hand tools, chainsaws, pumps and hoses. The terrain and the weather affect how a fire is fought.

Along with physical fitness, team cooperation and a courageous personality, forest firefighters need to use mathematics in order to get the job done quickly, safely and effectively.

Forest firefighters must be able to push their equipment to the absolute maximum. And that means knowing everything about it, notes Ralph Mohrmann, who works with a forest service protection program. This means that firefighters have to know all about water pumps, hose lines, nozzle pressure and friction loss.

There are lots of variables that could affect firefighters' equipment. Water pumps push water through the hose lines at various pressures. Pressure is measured in kilopascals (kPa). Each pump has a rated pressure maximum, and the firefighter must ensure that the pressure does not exceed that limit. Hoses and nozzles are designed to help put out fires by getting the right amount of water in the right form to the right place. Hoses and nozzles come in different sizes. In order for them to be effective, nozzle pressure must be carefully determined. If the water has to travel up an incline, this will increase the amount of pressure required to deliver it to the fire. Finally, as the water travels through the hose, it will lose some of its energy to friction. Depending on the hose and nozzle size, the firefighter must further calculate how much energy will be sacrificed due to friction. Firefighters use friction loss charts in their calculations. Make a wrong calculation and you risk letting the fire get out of control.

It sounds like fighting fires has a lot to do with working under "pressure" without causing too much "friction."

Practice

In groups of four or five, demonstrate the concepts of pressure and friction by completing the following activities.

Pressure: Puncture a two-liter plastic bottle with three equally small holes: one near the top, one near the middle and one near the bottom. Three of the group members should each place a thumb over each of the three holes, while a fourth fills the bottle with water. Ensure that the three people who are blocking the holes have graduated cylinders. At the given signal, the three will simultaneously take their thumbs away from the holes and catch the draining water with their graduated cylinder. After a 15-second count, simultaneously they will once again cover the holes. Record the volume of water in each of the graduated cylinders -- be sure to indicate which hole the water came from.

Friction: Using masking tape, mark off a one-meter distance on a carpeted surface and another one-meter distance on an uncarpeted surface. Place a battery-operated car at the starting line on the carpeted surface and record how much time it takes to cross the finishing line. (To increase the precision of your data, you may use a stopwatch.) Repeat this process on the uncarpeted surface.

Principles

As a group, discuss the following:

- What differences did you notice in the three volumes of water?
- What are some of the factors that might have influenced these differences?
- How does this relate to the concept of pressure?
- What differences did you notice between the car's time on the carpeted and uncarpeted surfaces?
- What are some of the factors that might have influenced these differences?
- How does this relate to the concept of friction?

Learn

Now make the connections between your demonstrations and the real-life situation facing forest firefighters. Answer the following questions:

- How many different ways can you affect the volume of water from an ordinary garden hose? How is this similar to fighting fires?
- Brainstorm five other things that use or require pressure to work.
- What does the diameter of a straw have to do with how easily you can drink a thick milkshake? How is this similar to fighting fires?
- Brainstorm five other things that are influenced by friction.

Yes, you can do it

A small fire has broken out and you're leading a crew of firefighters to put it out. You have two portable water pumps available. One has a rated pressure maximum of 1,500 kPa and the other can handle a capacity of 1,000 kPa. To determine which pump is better to use on this fire, you must use the following formula.

pump pressure = nozzle pressure + incline pressure + friction loss

You already know that the forest service requires the nozzle pressure to be 172.5 kPa.

There is a big hill between your water source and the fire, and you've estimated it to be an elevation difference of about 76 meters. You know that the quick rule for determining incline pressure is that it takes 10.5 kPa of pressure to push water up every one meter of elevation.

The fire is about 762 meters away. According to your friction loss charts, the hose and nozzle you are using cause 13.75 kPa of pressure to be lost per 30.5 meters due to friction.

Determine which pump you will use.

Additional Activities

You can try the math again using the ratings for a different type of hose. Get the numbers from the Friction Loss Chart below.

Firefighters use a combination of two types of hoses: lined and unlined. Lined hoses are nylon hoses that have a rubber lining in them. Lined hoses have less "weeping" and the water moves through them with less friction, says Mohrmann. "You don't need a pump with a big capacity for a lined hose."

An unlined hose requires a bigger pump because there's more friction. There's also more weeping, which keeps the hose wet. This way, there's less of a concern that the hose will be burned by the fire.

Curriculum Organizer: Number operations, patterns and relations, and problem solving	Curriculum Sub-organizer(s): Solving problems with formulae
Prerequisites: Simple equations and units of measure	Resources: - Two-liter plastic bottles - Graduated cylinders - Battery-operated cars - Stopwatches - Calculators

Solution to Learn

You want to determine the pump pressure, or capacity, that you will need in order to deliver water to the fire.

pump pressure = nozzle pressure + incline pressure + friction loss

nozzle pressure = 172.50 kPa

$$\text{incline pressure} = \frac{10.5\ \text{kPa}}{\text{m} \times 76\ \text{m}}$$

incline pressure = 798 kPa

$$\text{friction loss} = \frac{13.75\ \text{kPa}}{30.5\ \text{m}}$$

$$\text{friction loss} = \frac{762\ \text{m}}{30.5\ \text{m} \times 13.75\ \text{kPa}}$$

friction loss = 343.47 kPa

pump pressure = 172.50 kPa + 798 kPa = 343.47 kPa

pump pressure = 1313.97 kPa

A pump of at least 1313.97 capacity will be needed to deliver a minimum 172.50 kPa, so you must choose the pump which has a capacity to pump water at 1500 kPa.

Friction Loss Calculations for Forest Service Hose
at Various Nozzle Pressures Using a Variety of Nozzle Tip Sizes

25 mm (1 in) Lined Hose									
At Nozzle Pressure		Friction Loss Experienced for Every 30.5 Meters (100 Feet) of Hose Using Various Nozzle Sizes							
(kPa)	**(psi)**	**.635 cm**	**1/4 in**	**.7937 cm**	**5/16 in**	**.95 cm**	**3/8 in**	**1.25 cm**	**1/2 in**
138.00	20.00	13.75	2.0	24.00	3.5	57.25	8	227.50	33
172.50	25.00	17.25	2.5	38.00	5.5	32.75	12	269.00	39
207.00	30.00	20.75	3.0	51.75	7.5	110.30	16	317.25	46
241.25	35.00	27.50	4.0	62.00	9.0	124.00	18	386.00	56
275.75	40.00	34.50	5.0	76.00	11.0	151.75	22	420.50	61
344.75	50.00	41.50	6.0	89.75	13.0	179.25	26	503.25	73
413.75	60.00	48.25	7.0	103.50	15.0	213.75	31	592.75	86
38 mm (1 1/2 in) Lined Hose									
At Nozzle Pressure		Friction Loss Experienced for Every 30.5 Meters (100 Feet) of Hose Using Various Nozzle Sizes Different Nozzle Tip Sizes							
(kPa)	**(psi)**	**.635 cm**	**1/4 in**	**.7934 cm**	**5/16 in**	**.95 cm**	**3/8 in**	**1.25 cm**	**1/2 in**

138.00	20.00	3.50	0.5	05.50	0.8	10.50	1.5	27.50	4.0
172.50	25.00	4.25	0.6	07.00	1.0	13.75	2.0	34.50	5.0
207.00	03.00	4.75	0.7	09.00	1.3	16.50	2.4	42.00	6.1
241.25	53.00	5.50	0.8	10.50	1.5	19.50	2.8	49.00	7.1
275.75	40.00	6.25	0.9	12.50	1.8	22.00	3.2	56.50	8.2
344.75	50.00	7.00	1.0	14.50	2.1	24.75	3.6	69.00	10.0
413.75	60.00	8.25	1.2	16.00	2.3	27.50	4.0	82.75	12.0
38 mm (1 1/2 in) Unlined Hose									
(kPa)	**(psi)**	**.635 cm**	**1/4 in**	**.7934 cm**	**5/16 in**	**.95 cm**	**3/8 in**	**1.25 cm**	**1/2 in**
138.00	20.00	4.75	0.7	11.00	1.6	22.00	3.2	58.00	8.4
172.50	25.00	5.50	0.8	14.50	2.1	28.25	4.1	68.00	10.0
207.00	30.00	7.00	1.0	17.92	2.6	34.50	5.0	96.50	14.0
241.25	35.00	8.25	1.2	21.50	3.1	41.50	6.0	110.50	16.0
275.75	40.00	10.50	1.5	24.75	3.6	47.00	6.8	124.00	18.0
344.75	50.00	12.50	1.8	27.50	4.0	52.50	7.6	145.00	21.0
413.75	60.00	13.75	2.0	31.75	4.6	58.00	8.4	172.00	25.0