Can Nanotechnology Help Clean Up Ocean Oil Spills

Science Film Festival
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The enormous task of cleaning up oil spills in oceans and seas has burdened industry, government, and environmentalists for decades. The cleanup is almost always difficult. It involves great amounts of time, resources, and money to remove the oil from the water, and the cleanup is often only partially successful.

Today, however, scientists are coming to the rescue, developing a new technique that combines nanotechnology and magnetism. In this science project, you will test the proposed technique yourself. Will you succeed in separating oil from water?

TIME REQUIRED

Very Short (≤ 1 day)

Oil spills at sea are a serious hazard, causing enormous ecological damage. Billions of dollars are spent on cleanup operations, which do not always completely remove the oil from the environment. Could a novel idea combining nanotechnology and magnetism come to the rescue?

Magnetism, or the study of physical forces accompanying magnets, has intrigued people for ages. The ability of magnets to exert a force (a pull or push) at a distance is fascinating and even mind-boggling.

Nanoscience, or the study of phenomena only a couple of nanometers small, is a more recent addition to the world of science fields. A nanometer is 1 billionth (10-9) of a meter long. Nano-sized substances are about 50,000 to 100,000 times smaller than the width of a human hair. They differ in surprising ways from their larger-scale forms, making it hard for most of us to imagine – let alone understand – how things work at the nanoscale. Surprises are lurking at every corner. Imagine being a tiny insect – a common liquid like water might seem thick and gooey to you, and you might very well be able to walk over it. Quite different from our experience with water, right? Are insects a couple of nanometers long? No! But some are equipped with nanoscale tools giving them extraordinary capacities

Now, what if we brought magnetism and nanoscience together. Would magnetic material still exert magnetic properties if we reduced it to nanoparticles? If so, what other characteristics would these nanoparticles have?

Scientists have tested this hypothesis and have demonstrated they can create particles a couple of nanometers long that exhibit magnetic properties.

One interesting aspect of these magnetic nanoparticles is their ability to stay suspended in liquids, creating a ferromagnetic fluid or ferrofluid. What is so unique about that? Have you ever put iron filings in oil or water? Did they float, sink, or stay suspended? They sink, eventually. Until recently, there was no way to create a fluid that had magnetic properties.

The ingredient list of ferrofluids is surprisingly short: a liquid (referred to as the carrier fluid), ferromagnetic nanoparticles, and a surfactant or soap-like substance to keep the nanoparticles from clumping together. Different types of oil or water are frequently used as carrier fluids.

When no strong magnetic field is present, the ferrofluid flows as we expect liquids to flow. However, when a strong magnet (or magnetic field) is introduced, the ferrofluid is pulled to the magnet and unexpected things happen. You might well see the ferrofluid "jump" to the magnet, where it might create beautiful spike-like structures defying gravity.

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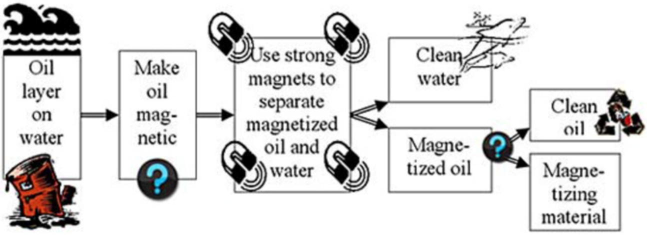
Ferromagnetic fluids have found their way into various practical uses such as electronic devices, medical \applications, and even art. Could this messy fluid help clean up oil spills at sea?

The idea is to somehow make the spilled oil magnetic, so strong magnets could be used to separate the magnetic oil from the non-magnetic water.

The illustration shows a flow chart explaining the method.



More recently, scientists have been working on the possibility of using ferromagnetic fluids to literally magnetize the oil. In this nanotechnology science project, you will explore the latter technique on a small scale. You will investigate how efficient the method is in removing oil from the surface of water, and you might reveal some of its limitations and strengths.

As mentioned, you will add ferrofluid to the spilled oil to make it magnetic. Your goal is to have the ferromagnetic particles from the ferrofluid spread and mix with the spilled oil, making it magnetic. If a carrier fluid is chosen such that it mixes well with the spilled oil, the ferrofluid will naturally spread and mix with the oil spill. You will then use a strong magnet to remove the oil/ferrofluid mixture from the water.

This science project idea aims not only to investigate if the method works on a small scale, but it also seeks to quantify how efficient the method is in removing oil from water at this scale. The volume of oil removed using this clean-up procedure will be compared to the volume of the original oil spill and quantified in a variable called "efficiency", as shown in **Equation 1**:

$$efficiency = \frac{\text{volume of removed oil}}{\text{volume of original spill}}$$

An efficiency value close to 1 means that almost all of the oil has been removed – this indicates that the cleanup method works well in removing the spilled oil from the water. An efficiency value close to 0 means that little of the original oil has been removed – indicating that the cleanup method does poorly in removing spilled oil from the surface of the water.

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Given that it is easier to measure the volume of oil left after the cleanup procedure, are you able to use your algebra and express the efficiency in function of the volume of leftover oil? (Hint : You will need the equation volume of original spill = volume of leftover oil + volume of removed oil).

Here are the resulting equations:

$$efficiency = \frac{\text{volume of original spill} - \text{volume of leftover oil}}{\text{volume of original spill}}$$

or

$$efficiency = 1 - \frac{\text{volume of left over oil}}{\text{volume of original spill}}$$

Review the table before you go ahead and spill some oil, add some ferrofluid to the mess, and see if a strong magnet can clean it all up.

What I Know	What I Want to Learn	What I Learned
Ferrofluids have ferromagnetic nanoparticles suspendend in a carrier fluid. Ferrofluids can be made from different carrier fluids. Frequently used carrier fluids are mineral oil, synthetic oil, and water. Ferrofluids are attracted to magnets.	Can ferrofluids with an oil carrier fluid be used to seperate oil from water? How efficient is or what portion of the oil can be removed using this method? What other restrictions or difficulties need to be overcome to make this method appli-cable to clean up oil spills on sea?	

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TERMS AND CONCEPTS

- **Magnetism**
- **Force**
- **Nanoscience**
- **Nanometer**
- **Suspended**
- **Ferromagnetic fluid**
- **Ferrofluid**
- **Carrier fluid**
- **Surfactant**
- **Efficiency**

QUESTIONS

- **What are the main characteristics of a ferrofluid and what is it made of?**
- **What carrier fluids are commonly used to create a ferrofluid?**
- **Although this project uses an oil-based ferrofluid, would a water-based ferrofluid work to magnetize the oil in the oil spill?**
- **Would it be possible to create a ferrofluid by adding iron filings to oil or another fluid? Why or why not?**
- **What criteria could be used to evaluate if the method tested is a good candidate to be used to clean up oil spills at sea?**

MATERIALS AND EQUIPMENT

- Ferrofluid, 50 mL (Note: make sure it uses mineral oil as its carrier fluid)
- Mineral oil, 60 mL
- Neodymium block magnet
- Petri dishes, 90 mm x 15 mm (10)
- Graduated cylinder, 25 mL volume
- Plastic transfer pipettes, graduated (10)
- Nitrile gloves, pairs (3)
- Apron or clothes that can be stained
- Poster board, preferably white
- Lab notebook and pen
- Water (tap water is fine)
- Cups (3). Two should hold at least 150 ml, the third should hold at least 30 ml.
- 2 drops of food coloring (any color)
- Cloth rag or paper towels
- Sink or bowl (to wash the graduated cylinder and petri dishes after use)
- Hot water
- Dishwashing liquid
- Plastic sandwich bags (9)
- Drinking straws (3)
- Paper or plastic bag for trash

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Safety Instructions

Neodymium magnets are very strong. Some have the capacity to interfere or reset pacemakers. Never put a neodymium magnet in your mouth. Always keep them away from computers, credit cards, and other magnetized objects.

EXPERIMENTAL PROCEDURE

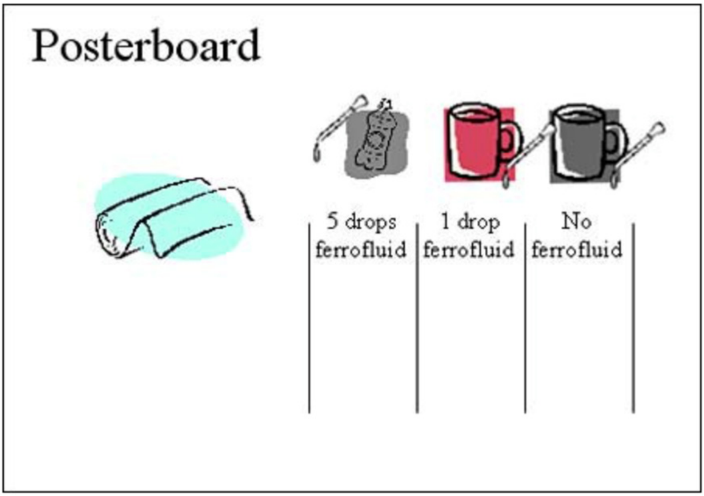
In this science project, you will test a novel method to clean up oil spills from water using a ferrofluid and a strong magnet. Note that ferrofluids are messy. They stain skin as well as clothes and surfaces. Throughout the procedure, take measures to contain the ferrofluid. Before you start, though, put on an apron and check yourself and your environment: Would it be OK if some ferrofluid spills on your clothes or your work surface?

You will be using a neodymium magnet. These magnets are strong. At all times, keep these magnets away from any magnetized material and computers.

1. Prepare the work area.

a) Put a white poster board on the ground or the table where you will work. The poster board will protect the surface, provide a clean background for pictures, and enable you to take notes.

b) Make three columns near the middle of the poster board by drawing four vertical lines, about 4 inches wide and 8 inches long. Title the columns "5 drops ferrofluid," "1 drop ferrofluid," and "No ferrofluid." Figure 4 shows how to organize your work area.



2. Copy the following table in your notebook. You will use it to record your measurements:

Volume of Mineral Oil Left after Cleaning Procedure (mL)			
	Control: Cleaning procedure without use of ferrofluid	Cleaning procedure using 1 drop of ferrofluid	Cleaning procedure using 5 drops of ferrofluid
Test 1			
Test 2			
Test 3			
Average			
Efficiency			
Observations			

3. Prepare your water. Use colored water to increase visibility.

a) Fill a cup with at least 100 milliliters (mL) of tap water.
b) Add one or two drops of food coloring to the water.
c) Mix so the food coloring dissolves in the water.
d) Put the cup above the columns as shown in Figure 4.
e) Place a pipette next to it. This pipette will only be used for the colored water.

4. Prepare the mineral oil.

a) Pour about 25 mL of mineral oil in a small cup. Having the oil in a cup will make it easier to use your pipette.
b) Put the cup above the columns, next to the cup with colored water.
c) Place a graduated pipette next to it. This pipette will only be used for the mineral oil.

5. Prepare the ferrofluid

a) Put the bottle with ferrofluid next to the other two cups, above the columns on your posterboard.
b) Place a pipette next to it on a cloth or paper towel. This pipette will only be used for the ferrofluid.
c) Have a cloth or paper towel ready to clean up any spilled ferrofluid.
d) Put on gloves.

6. Prepare to wash out your graduated cylinder.

a) Fill the sink or a large bowl with warm water.
b) Add dishwashing liquid to the water.

7. Have an empty cup ready to hold discarded fluid.

8. Prepare your test.

a) Put one petri dish in each column, three in total.
b) Use a pipette to fill each petri dish with about 14 mL of the colored water. If you are using a different size of petri dish, fill the petri dishes until the water level is a couple of millimeters high.
c) Use the graduated pipette to add exactly 2.5 mL of mineral oil to each of the Petri dishes. This represents your oil spill.
i. It is important that each petri dish receive exactly the same volume of oil so the results can be compared against each other.
ii. Aim to release the oil near the middle of the petri dish.

9. Make the oil magnetic by adding ferrofluid.

a) Shake the bottle of ferrofluid before opening.
b) Test how it feels to let one drop out of the pipette back into the bottle.
c) For the petri dish in the “1 drop ferrofluid” column, place one drop of ferrofluid in the middle of the oil spill.
d) For the petri dish in the “5 drops ferrofluid” column, place five drops of ferrofluid in the oil spill, preferably distributed over the oil surface.
- **i.** If a drop falls on the water surface instead of the oil spill, observe what happens. (Does the ferrofluid float on the water? Does it sink?) Make a special note in your notebook. This information will be valuable when analyzing your data.

e) Close the ferrofluid bottle and place the pipette on the cloth or paper towel next to it.
f) Note that you will not add ferrofluid to the petri dish in the column titled “no ferrofluid.” You will use this petri dish as a control and reference.
g) Wait and observe for about one minute. Does the ferrofluid distribute itself over the oil spill? Does it go into the water? Do you see ferrofluid sinking to the bottom of the petri dish?

10. Clean up the oil spill with a magnet.

a) Repeat the following cleanup procedure for all three petri dishes, starting with the one above the column titled "No ferrofluid added."

i. Open a clean plastic sandwich bag.
ii. Put the neodymium magnet in one of the corners of the plastic bag.
iii. Move the magnet enclosed in the sandwich bag through the oil in one movement. It works best to slightly submerge the magnet in the liquid and try to pass through the complete oil spill in one movement as best you can. Note: It is important to choose one method of moving the magnet through (or over) the oil spill and then stay with it throughout this project. You want to compare the efficiency using different amounts of ferrofluid. Different methods of moving the magnet through the fluid might influence the results.
iv. Wipe the bag off on a paper towel or cloth.
v. Put the magnet in the other corner of the plastic bag. This corner should still be clean and dry; if not, use a new bag.
vi. Pass the magnet in the bag through the oil a second time.
vii. Wipe the bag off on a paper towel or cloth and put it in the trash bag.
viii. Write any special observations in your notebook. Does the leftover oil look clean or dirty? Is there any ferrofluid left in the liquid left in the petri dish? If so – is it floating, sinking, or suspended?

11. Measure how much oil is left on the water.

a) Repeat the following procedure for all three petri dishes.

i. Carefully transfer all of the leftover liquid (water, oil, and ferrofluid) from the petri dish to the graduated cylinder. Some oil will stick to the petri dish. Try to get as much as possible in the cylinder. Do not use a funnel, as more oil would stick to the funnel and lower the readings even more.
ii. Wait till all of the oil settles on top of the water in the cylinder.
iii. Read the amount of oil left on top of the water. Make sure you have the oil layer leve with your eye. The oil layer can have a curved shape.
iv. Record your reading in a table similar to Table 2 in the appropriate column.
v. Add observation notes where needed. Make observations that might be important when transferring the technique to cleaning up oil on the sea.
vi. Discard the fluid from the cylinder in a cup.
vii. Wash your cylinder carefully with the warm, soapy water.
viii. Dry the inside of your cylinder with a paper towel wrapped around a drinking **straw.**

12. Empty your cup with the discarded fluid in a sink or toilet, and place the used petri dishes in a pile to wash later.

13. Repeat steps 8 through 12 two more times for a total of three tests for each cleaning procedure.

14. Tidy up the workspace, wash the petri dishes and cylinder, and discard all dirty paper towels and cloths as well as the pipette used to transfer the ferrofluid.

15. Analyze your data.

a) Calculate the average volume of leftover mineral oil from the three tests and record the results in your data table.

b) Calculate the efficiency of the cleanup procedures and record the values in your data table. If you need a refresher, look back in the Introduction tab for the definition and equations of efficiency. For your convenience, Equation 3 is repeated, with the volume of the original oil spill replaced by the amount used in this test, i.e. 2.5 mL. Use the average amount (in milliliters) of oil left over after cleanup to calculate the efficiency.

$$efficiency = 1 - \frac{\text{volume of leftover oil (mL)}}{2.5\ \text{mL}}$$

c) Make a bar graph of the data.

i. Make a bar graph of the volume left over for the two cleanup procedures and the control (the one with no ferrofluid).

ii. Make a bar graph of the efficiency of each cleanup procedure and the control.

iii. You can make your graphs by hand or use a website like Create A Graph to make the graphs on a computer and print them. You can also use a spreadsheet program like Microsoft Excel.

d) Does your data confirm that a ferrofluid can be used in conjunction with a strong magnet to remove an oil spill from water on the small scale tested?

16. Thoughts and conclusions.

a) How does the control compare to the cleanup using one drop of ferrofluid and the cleanup using five drops of ferrofluid?

b) Do you see some shortcomings to your tests? Things to think about:

i. Does the oil left on the petri dish when transferring the fluid to the graduated cylinder influence your measurements? Would they bias your results in a systematic way? If so, do they make your efficiency look better or worse?

ii. What does the efficiency of the control tell you?

iii. Is it still possible to compare the control with the different cleanup methods and draw conclusions?

c) Would you classify the method efficient on this scale? Would applying this method on a bigger scale automatically yield similar efficiencies?

d) Which advantages, shortcomings, and points to work on did you identify for using a ferrofluid to clean up oil spills on water?

e) In what ways could you improve the method?

f) Seeing your results, do you think it is worth investigating the method at a much larger scale with the objective of using it to clean up oil spills at sea? Would you say specific points need to be improved and/or investigated before proceeding?

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VARIATIONS

- In this science project, the water in the petri dish was still. No waves or movement disturbed the oil spill. Investigate whether moving the petri dish around, creating small waves, or stirring the liquid in the petri dish has an influence on the efficiency of the cleanup procedure. Investigate what happens if ferrofluid accidentally drops on the water instead of on the oil spill. Will it sink and cause an environmental hazard?
- This science project tested the cleanup of mineral oil on water using a mineral oil-based ferrofluid. Test how efficiently the method works cleaning up vegetable oil or other types of oil or, alternatively, buy a ferrofluid based on a different carrier fluid and test how well this ferrofluid works to clean up oil spills.
- In this science project, it is suggested that you submerge the magnet in the liquid. Alternatively, investigate what works best: submerging the magnet in the liquid; barely touching the surface; or hovering over the surface with the magnet? In another variation, study the effect of moving your magnet fast or slow through or over the liquid. In these cases, it is important to keep the number of drops of ferrofluid used in the cleanup constant, as your aim is to compare different ways of moving the magnet.
- This science project tested cleanup procedures using a bar neodymium magnet. Could you try the method using different strengths of magnets? Or different shapes of magnets? Would the surface area of the magnet play an important role? In these cases, it is important to stick to a particular number of drops of ferrofluid for the cleanup as, in this case, you want to determine any difference caused by switching magnets.
- In this science project, you used one or five drops of ferrofluid to clean up an oil spill of 2.5 mL. Could you investigate if the efficiency is the same if you double or triple all quantities (e.g., comparing the efficiency when using one drop to clean up 2.5 mL of oil, two drops to clean up 5 mL of oil, and three drops to clean up 7.5 mL of oil.)
- For a more advanced project, look up how people make ferrofluid themselves with jet-printer ink. Would you be able to make your own ferrofluid and optimize it to clean up a specific oil spill?

Authors/Source
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