FERROFLUIDS to the Rescue!

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ABSTRACT

The purpose of my science fair project was to study the effects of different amounts of ferrofluid distributed over the oil on a neodymium magnet's ability to efficiently separate the oil from the water. My hypothesis for this project was that if I increase the amount of ferrofluid distributed over the oil's surface than the efficiency of oil removed from the water will increase, because there will be a stronger magnetic force between the neodymium magnet and the magnetized oil.

The constants in my experiment was the amount of water, the amount and type of mineral oil, type of ferrofluid, size of the petri dish, size of the graduated cylinder, and size of the pipette. The control group in my experiment was the petri dish with no ferrofluid. The variable I changed or the independent variable of my project was the amount of ferrofluid distributed over the oil's surface. The variable I measured/ dependent variable was the efficiency and the volume of oil left on the water's surface. The scientific tool I used to measure the volume of oil left over was using a graduated cylinder. After the cleaning procedure, I would carefully transfer the remaining liquid from the petri dish to the graduated cylinder. Then, I would measure the volume of oil using the graduations. To measure the efficiency, I used the following formula

Efficiency = 1– volume of leftover oil (mL) / 2.5 ml (volume of original amount of mineral oil.)

In all three trials the neodymium magnet was able to separate the most amount of oil from the petri dish with 10 drops of ferrofluid. The average amount of mineral oil left over after cleaning procedure with the petri dish with 0 drops, 2 drops, 5 drops, and 10 drops of ferrofluid was 2.33ml, 1.92ml, 1.33ml, and 0.92 ml respectively. The efficiency of the cleaning procedure using 0 drops, 2 drops, 5 drops, and 10 drops of ferrofluid was 0.07ml, 0.23ml, 0.47ml, and 0.63ml respectively. The results show that my hypothesis should be considered true, because the neodymium block magnet separated the most amount of mineral oil from the petri dish with 10 ml of ferrofluid leaving an average of 0.92ml of mineral oil left over and an efficiency of 0.63 ml. Also, the neodymium block magnet separated the least amount of mineral oil from the petri dish with 0 ml of ferrofluid leaving an average of 2.33ml of mineral oil left over and an efficiency of 0.07 ml.

The experimental error that could have led to erroneous result was the variation in the ways mineral oil spread over water in each trail. In every petri dish the mineral oil took a different form and sometimes it was clinging to the side of the petri dish that might have affected the efficiency of the cleaning procedure. Also, the graduated cylinder did not have more subdivision to get more precise results. If I were to repeat my experiment, I would get a glass cylinder with more graduations. Also, I would like to 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. This science project tested cleanup procedures using a bar neodymium magnet. I would like to try the method using different types of magnets with varying strength. It would be also interesting to further investigate if the surface area of the magnet plays an important role.

Oil spills 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. I think this novel idea of combining nanotechnology and magnetism could be used to clean up oil spills more efficiently.

Problem Statement

How does the amount of ferrofluid distributed over the oil affects the neodymium magnets' ability to efficiently separate the oil from the water?

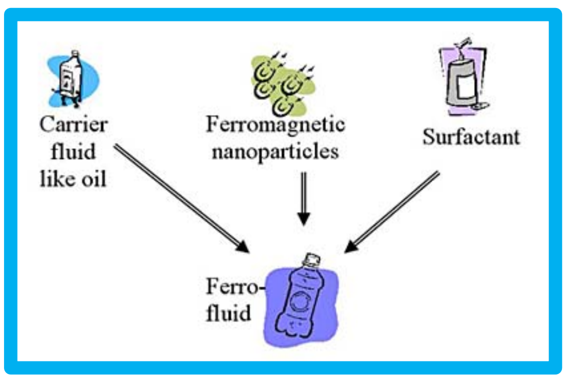
BACKGROUND RESEARCH

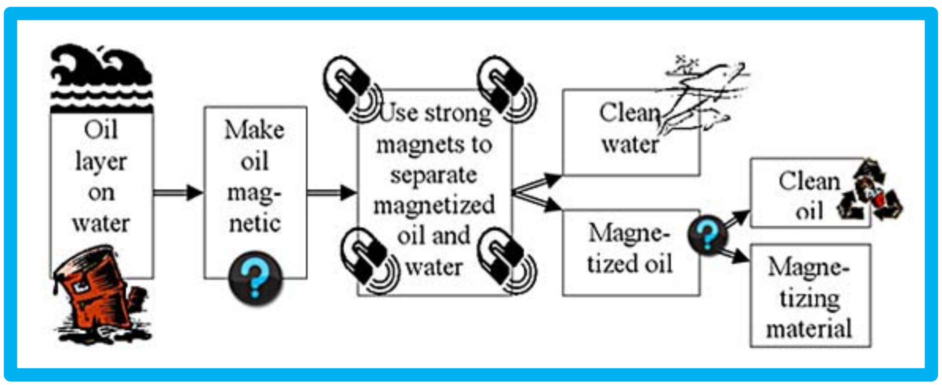
Ferrofluids are composed of magnetic nanoparticles, a special coating, and a water or oil-based liquid. Steve Papell, a NASA engineer invented the first ferrofluid in the early 1960's. Now, ferrofluids are found in skateboards, speakers, hard drives, and in the future, maybe biomedicine. (Alessandra Potenza) [1]

Oil Spills are one of the most hazardous disasters that effect the environment and marine life. In fact, according to the National Oceanic and Atmospheric Administration, thousands of oil spills occur each year.[2] Oil spills can occur when drilling operations go wrong, pipelines burst, and large oil tanker ships sink. [2] These oil spills cause fouling or oiling which can harm plants and animals dramatically. [2] If a bird's wings become coated with oil it will be unable to fly, or it can put otters at a chance of obtaining hypothermia. [2] Another way oil spills can affect the marine life is due to oil's toxic compounds, which can cause effects to the immune system, heart damage, diminutive growth, and sometimes death. (National Oceanic and Atmospheric Administration).[2]

There have been 2 methods used to clean oil spills until now – skimmers and chemical dispersants. Both of these methods have their drawbacks such as skimmers cam be hampered by harsh weather, and chemical dispersants can have negative effects on marine life. (Stanford Magnets) [5]

MIT researchers have now found a way to make cleaning oil spills more efficient by using magnets and ferrofluid. (Tom Levitt). [3] Ferrofluids are known as colloidal fluids and are composed of nanoscale ferromagnetic particles suspended in a carrier fluid, usually water or an organic solvent like kerosene, and coated with a surfactant to stop them clumping together in the liquid. A typical composition would be 5% magnetic particles, 10% surfactant and 85% carrier fluid. (MAGCRAFT)[6]





Using magnets to clean oil spills is a very efficient method. The cost of the cleanup is cheaper, you can reuse the oil and the nanoparticles, its less time consuming, and it involves less manual labor. (Larry Hardesty)[4]. MIT researchers plan to make the oil magnetic is by mixing it with ferrofluid or any water repellant nanoparticles that contain iron. (Tom Levitt) [3]. After the oil is separated from the water, we can use a magnet to sperate the oil from the ferrofluid, so we can conserve oil, saving money and fossil fuels. (Tom Levitt) [3]. This will be comparatively easy since ferrofluid and mineral oil have similar densities.

When there is more ferrofluid, there will be more magnetized nanoparticles, therefore allowing the magnet to attract more oil mixed with the ferrofluid. **More ferrofluid increases the reaction with magnets, increasing the attraction.** (UCSB Science Line) [7]. **Based on my background research on ferrofluid, and oil spills, I hypothesize that if I increase the amount of ferrofluid distributed over the oil's surface than the efficiency of oil removed from the water will increase, because there will be a stronger magnetic force between the neodymium magnet and the magnetized oil.**

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HYPOTHESIS

If I increase the amount of ferrofluid distributed over the oil's surface than the efficiency of oil removed from the water will increase, because there will be a stronger magnetic force between the neodymium magnet and the magnetized oil.

Variables

Independent/ Manipulated Variable - The amount of ferrofluid distributed over the oil's surface.

Dependent/ Respondent Variable: The efficiency and the volume of mineral oil left over on the water's surface.

Constant Variable (Constants):

- The amount of water.
- Type and size of the Neodymium Magnet.
- The amount of mineral oil.
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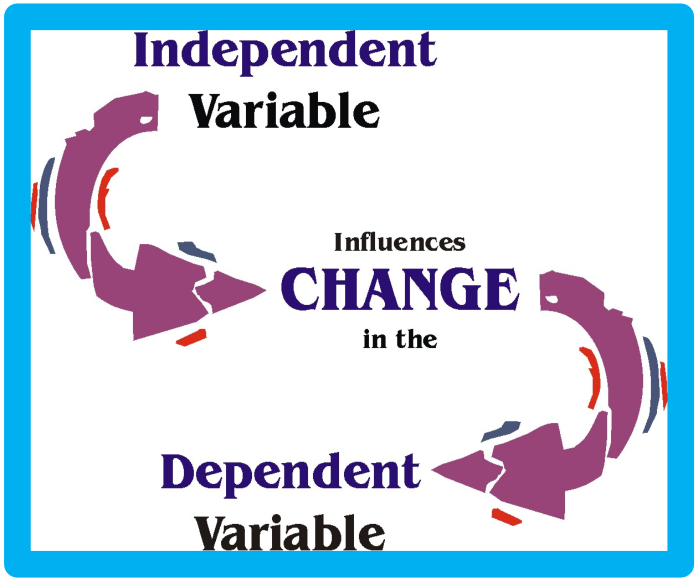
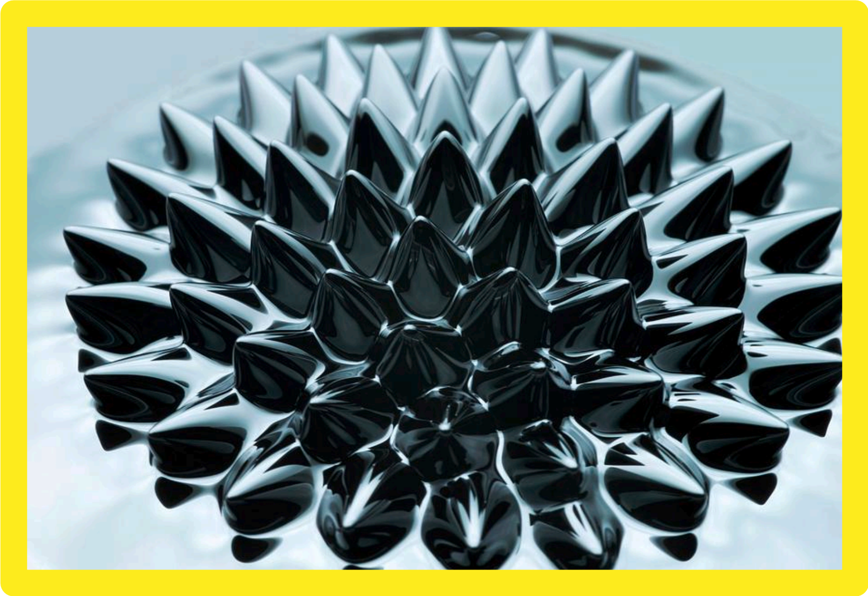
- Type of ferrofluid.
- Size of Petri Dishes.
- Method of moving the magnet through (or over) the oil spill



Control Group: The petri dish with no ferrofluid

MATERIALS

- 2 oz of mineral oil carrier base Ferrofluid.
- Mineral Oil, 60 ml
- 1 fl oz of Green Food Color.
- 40 x 40 x 20 mm Neodymium Block Magnet.
- 20 plastic Petri dishes, 90mm by 15 mm deep.
- 20 plastic transfer pipettes.
- 25 ml Glass Graduated Cylinder.
- Nitrile Gloves.
- Clothes that can be stained.
- 1 White Poster board.
- Water (tap water) & Hot water.
- 1 Lab notebook.
- 3 plastic cups (150 ml) & 1 Large bowl.
- Cloth rag or Paper towels.
- Dishwashing liquid.
- 12 plastic sandwich bags & Plastic trash bags.
- 1 Camera & 1 helper.



PROCEDURES

1. Prepare the work area.
   a) Put a white poster board on 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 four columns. Title the columns “10 drops ferrofluid "5 drops ferrofluid," "1 drop ferrofluid," and "No ferrofluid," from right to left. **Figure 1** shows how to organize your work area.
2. **Make a table** (**Table 1**) in your lab notebook. You will use it to record your measurements.
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 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 1**.
   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 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, four in total.
b) Use a pipette to fill each petri dish with 15 mL of the colored water.
c) Use the graduated pipette to add exactly 2.5 mL of mineral oil to each of the Petri dishes (**Figure 3**). This represents your oil spill. It is important that each petri dish receive exactly the same volume of oil so the results can be compared against each other. 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) Place 2 drops, 5 drops and 10 drops of ferrofluid in the middle of the oil spill in the petri dish in the "2 drops ferrofluid" column, "5 drops ferrofluid" column and "10 drops ferrofluid" column respectively. (**Figures 4 and 5**).
   d) If a drop falls on the water surface instead of the oil spill, observe what happens. Make a special note in your notebook.
   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?
   h) Optional: Take pictures.

10. **Clean up the oil spill with a magnet.** Repeat the following cleanup procedure for all four petri dishes, starting with the one above the column titled "No ferrofluid added."
   a) Open a clean plastic sandwich bag.
   b) Put the neodymium magnet in one of the corners of the plastic bag, as shown in **Figure 2.**
   c) 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.
   d) Wipe the bag off on a paper towel or cloth.
   e) 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.
   f) Pass the magnet in the bag through the oil a second time.
   g) Wipe the bag off on a paper towel or cloth and put it in the trash bag.

h) 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?
i) Take pictures.

11. Measure how much oil is left on the water: Repeat the following procedure for all four petri dishes.

a) 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.
b) Wait till all of the oil settles on top of the water in the cylinder.
c) Read the amount of oil left on top of the water. Make sure you have the oil layer level with your eye. The oil layer can have a curved shape. A close-up picture like the one shown in **Figure 6** can help you make readings more accurate.
d) Record your reading in **Table 1** in the appropriate column.
e) Add observation notes where needed. Make observations that might be important when transferring the technique to cleaning up oil on the sea.
f) Discard the fluid from the cylinder in a cup.
g) Wash your cylinder carefully with the warm, soapy water.
h) 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 trials 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 trials and record the results in your data table.
b) Calculate the efficiency of the cleanup procedures and record the values in your data table. Use the average amount (in milliliters) of oil left over after cleanup to calculate the efficiency.

Efficiency = 1– volume of leftover oil (mL) / 2.5 ml

16. Create graphs for your data (**Graphs 1,2 and 3**).

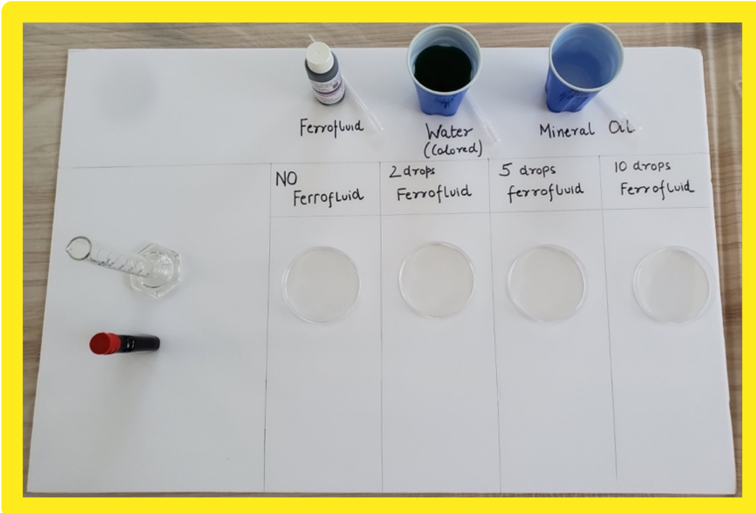


Figure 1. Organize your work area. Use a poster board as the surface to work on for this science project. Four columns indicate the test area. Above them are cups with water and mineral oil and a bottle of ferrofluid.

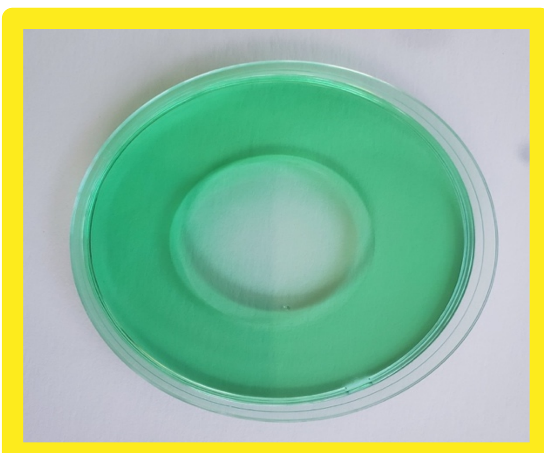


Figure 3. Use the graduated pipette to add exactly 2.5 mL of mineral oil to each of the Petri dishes Aim to release the oil near the middle of the 15ml water.

Figure 2. Place the neodymium magnet in the corner of the sandwich bag.

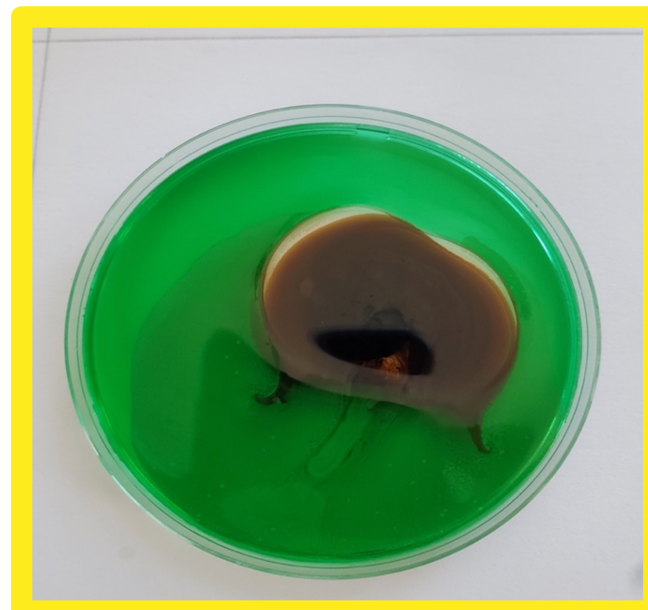


Figure 4. Place 5 drops of ferrofluid in the middle of the oil spill in the petri dish in the 5 drop ferrofluid" column

Figure 5. Place 2 drops, 5 drops and 10 drops of ferrofluid in the middle of the oil spill in the petri dish in the "2 drops ferrofluid" column, "5 drops ferrofluid" column and "10 drops ferrofluid" column respectively

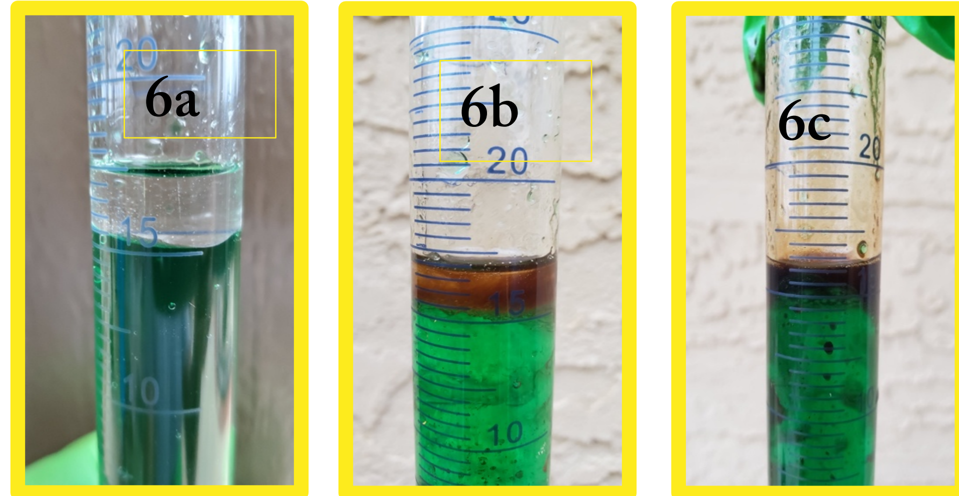


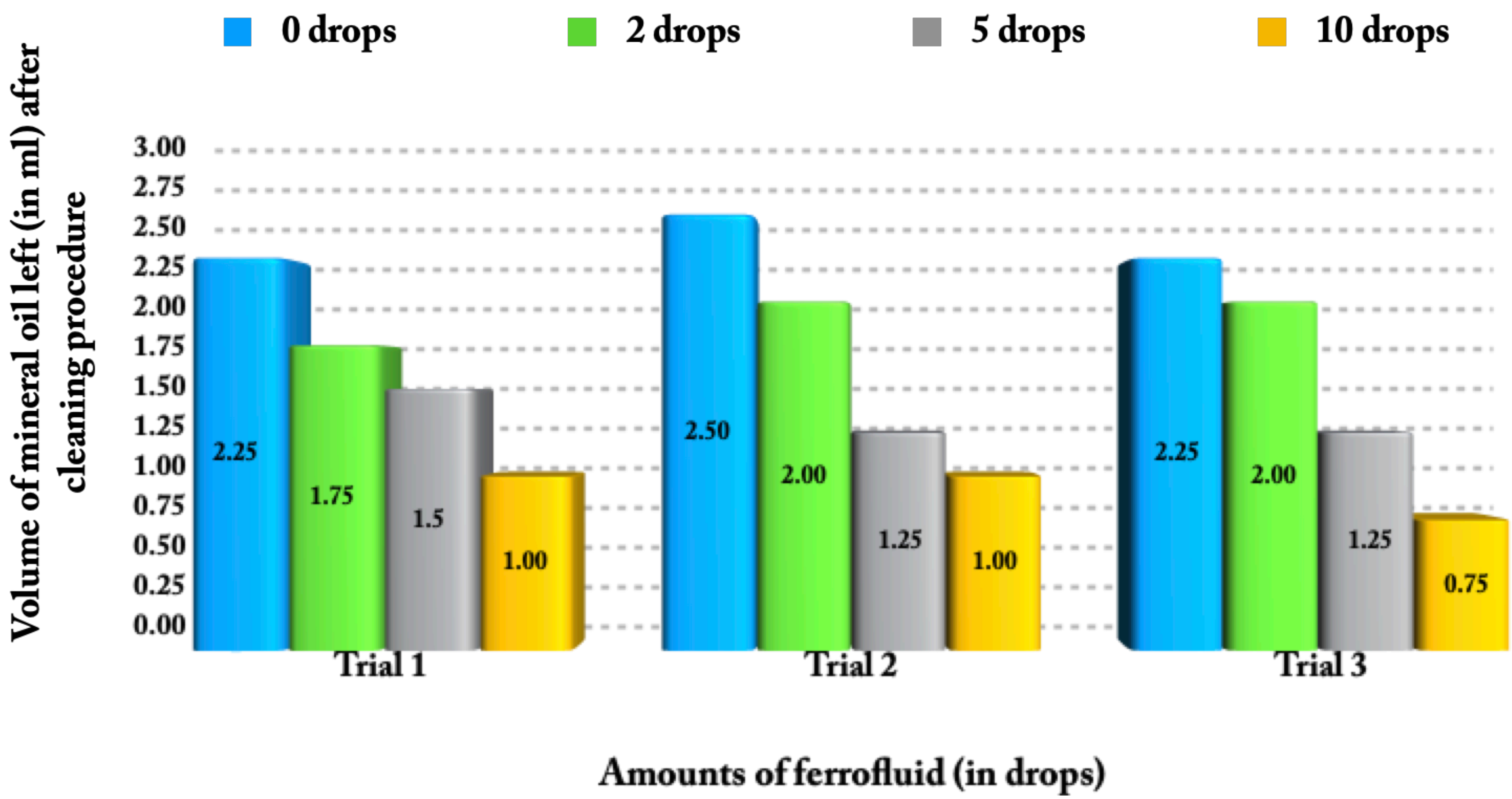
Figure 6. Read the amount of oil left on top of the water. Make sure you have the oil layer level with your eye.
a) 2.5 ml mineral oil left after cleaning procedure using 0 drops of ferrofluid (Control Group Trial 2).
b) 2.0 ml mineral oil left after cleaning procedure using 2 drops of ferrofluid (Trial 2).
c) 1.0 ml mineral oil left after cleaning procedure using 10 drops of ferrofluid (Trial 2).

DATA TABLE AND GRAPHS

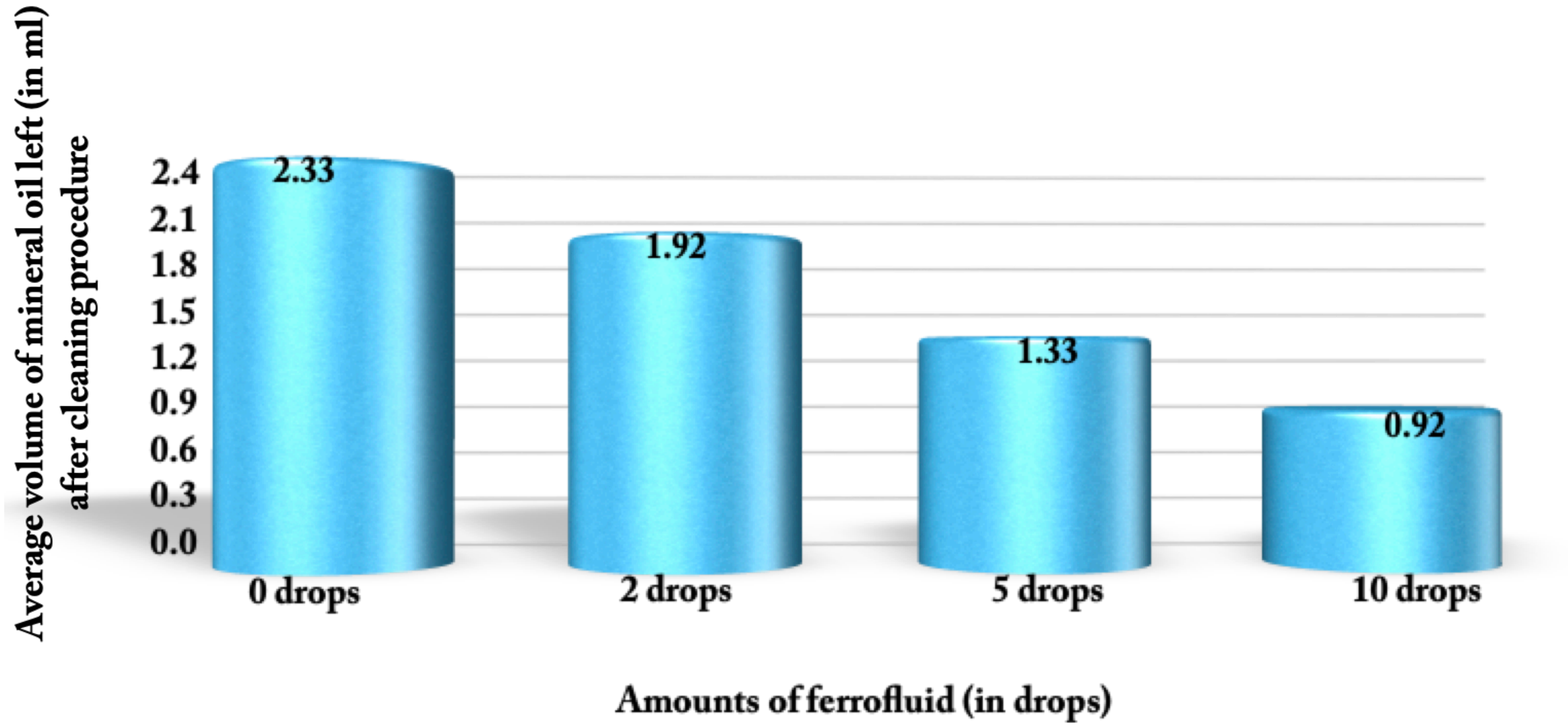
Amount (drops) of Ferrofluid used (Independent Variable)	0 drops	2 drops	5 drops	10 drops
Trial 1 (volume of mineral oil left in ml)	2.25	1.75	1.5	1.0
Trial 2 (volume of mineral oil left in ml)	2.5	2.0	1.25	1.0
Trial 3 (volume of mineral oil left (in ml)	2.25	2.0	1.25	0.75
Average	2.33	1.92	1.33	0.92
Efficiency	0.07	0.23	0.47	0.63

Table 1: Data table showing volume of mineral oil left (in ml) after cleaning procedure.

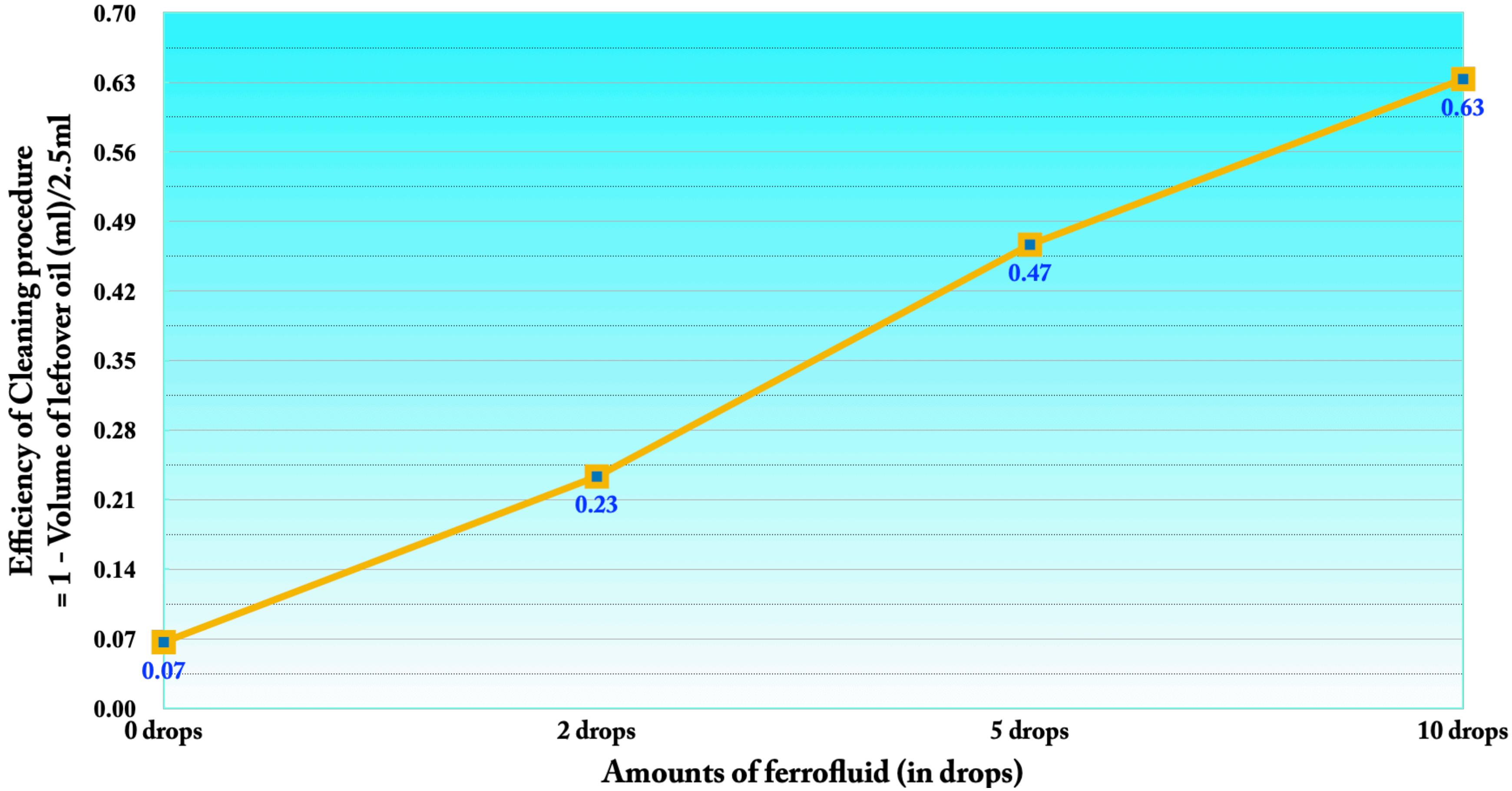
Graph 1. Graph showing volume of mineral oil left (in ml) after cleaning procedure in trials 1, 2 and 3.



Graph 2. Graph showing average volume of mineral oil left (in ml) after cleaning procedure using different amounts of ferrofluid (in drops).



Graph 3. Graph showing the efficiency of the cleaning procedures using different amounts of ferrofluid (in drops)



RESULTS

In my experiment, **I tested whether the amount of ferrofluid distributed over the oil affects the neodymium magnets' ability to efficiently separate the oil from the water.**

In all three trials, the neodymium magnet separated the least amount of oil from the petri dish with 0 drops of ferrofluid. In trial 1, the amount of oil left after the cleaning procedure was 2.25 ml, 1.75 ml, 1.5 ml, and 1.0 ml from the petri dish with 0 drops of ferrofluid, 2 drops, 5 drops, and 10 drops of ferrofluid respectively. In trial 2, the amount of oil left after the cleaning procedure was 2.5 ml, 2.0 ml, 1.25ml, and 1.0 ml from the petri dish with 0 drops of ferrofluid, 2 drops, 5 drops, and 10 drops of ferrofluid respectively. In trial 3, the amount of oil left after the cleaning procedure was 2.25 ml, 2.0 ml, 1.25ml, and 0.75 ml from the petri dish with 0 drops of ferrofluid, 2 drops, 5 drops, and 10 drops of ferrofluid respectively.

The average amount of mineral oil left over after cleaning procedure with the petri dish with 0 drops, 2 drops, 5 drops, and 10 drops of ferrofluid was 2.33ml, 1.92ml, 1.33ml, and 0.92 ml respectively.

The efficiency of the cleaning procedure using 0 drops, 2 drops, 5 drops, and 10 drops of ferrofluid was 0.07, 0.23, 0.47, and 0.63 respectively.

Conclusion

My hypothesis was, if I increase the amount of ferrofluid distributed over the oil's surface than the efficiency of oil removed from the water will increase, because there will be a stronger magnetic force between the neodymium magnet and the magnetized oil.

The results indicate that this hypothesis should be considered true, because the neodymium magnet was able to separate the most amount of mineral oil from the petri dish with the most ferrofluid (10 drops) with an average of 0.92 ml of mineral oil left and an efficiency of 0.63.

The experimental error that could have led to erroneous result was the variation in the ways mineral oil spread over water in each trail. In every petri dish the mineral oil took a different form and sometimes it was clinging to the side of the petri dish that might have affected the efficiency of the cleaning procedure. Also, the graduated cylinder did not have more subdivision to get more precise results. If I were to repeat my experiment, I would get a glass cylinder with more graduations. Also, I would like to 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. This science project tested cleanup procedures using a bar neodymium magnet. I would like to try the method using different types of magnets with varying strength. It would be also interesting to further investigate if the surface area of the magnet plays an important role.

In conclusion, this experiment taught me how you can efficiently remove oil from water using nanoscience and magnetism. I was able to learn important scientific concepts behind ferrofluids, nanoparticles and ferromagnetism. I also learned about the harmful effects of oil spills on our ecosystem and different methods currently used to clean oil spills. Oil spills 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. I think this novel idea of combining nanotechnology and magnetism could be used to clean up oil spills more efficiently (**Image 1**).

A better understanding of science behind the ferrofluid is necessary because they are used in various critical areas. Ferrofluid enables audio speakers to function more efficiently, with improved audio response and better power handling (**Image 2**). In medicine, magnetic nanoparticles may be incorporated into polymer microspheres (which are coated with antibodies and/or therapeutic/chemotherapy drugs), injected into tissues and then drawn to the site of a lesion using a strong magnetic field **Image 3**. Magnetic nanoparticles are also used for contrast enhancement in Magnetic Resonance Imaging (MRI) Image. Magnetic nanoparticle can also be used therapeutic hyperthermia which is a cancer therapy which consists in heating selectively tumor zones. Those zones have less blood vessels and are less oxygenated than health ones. Consequently, they are more sensible and died when the local temperature increases above 43°C. In this approach, Magnetic nanoparticles (NMPs) are firstly introduced into the desired tissues and then guided by an external magnetic field. An externally applied oscillating magnetic field induces the hyperthermia as illustrated in **Image 4**.

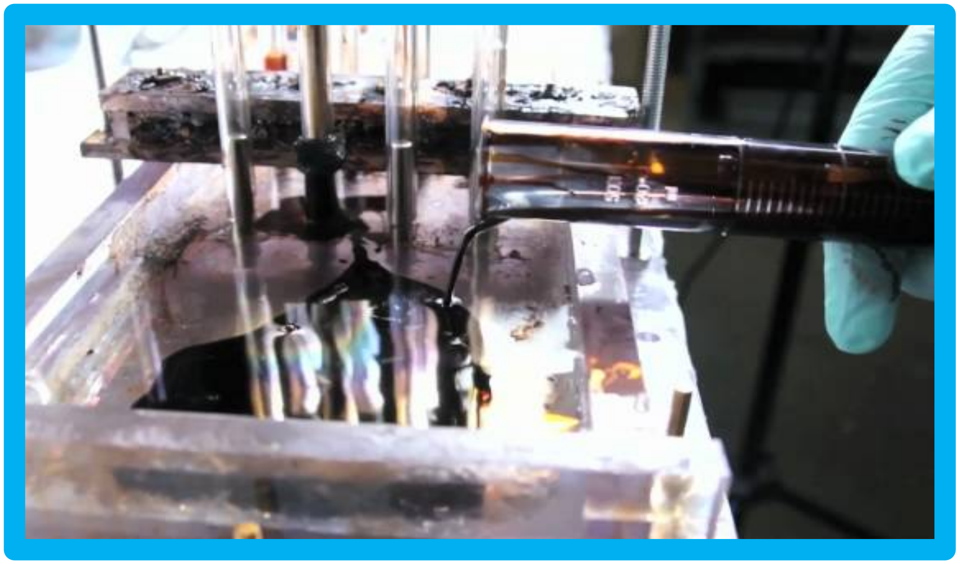


Image 1. MIT researchers have developed a new technique for magnetically separating oil and water that could be used to clean up oil spills. They believe that, with their technique, the oil could be recovered for use, offsetting much of the cost of cleanup. Image Credit Hardesty, Larry "How to clean up oil spills" MIT News Office, 2012 - https://news.mit.edu/2012/how-to-clean-up-oil-spills-0912

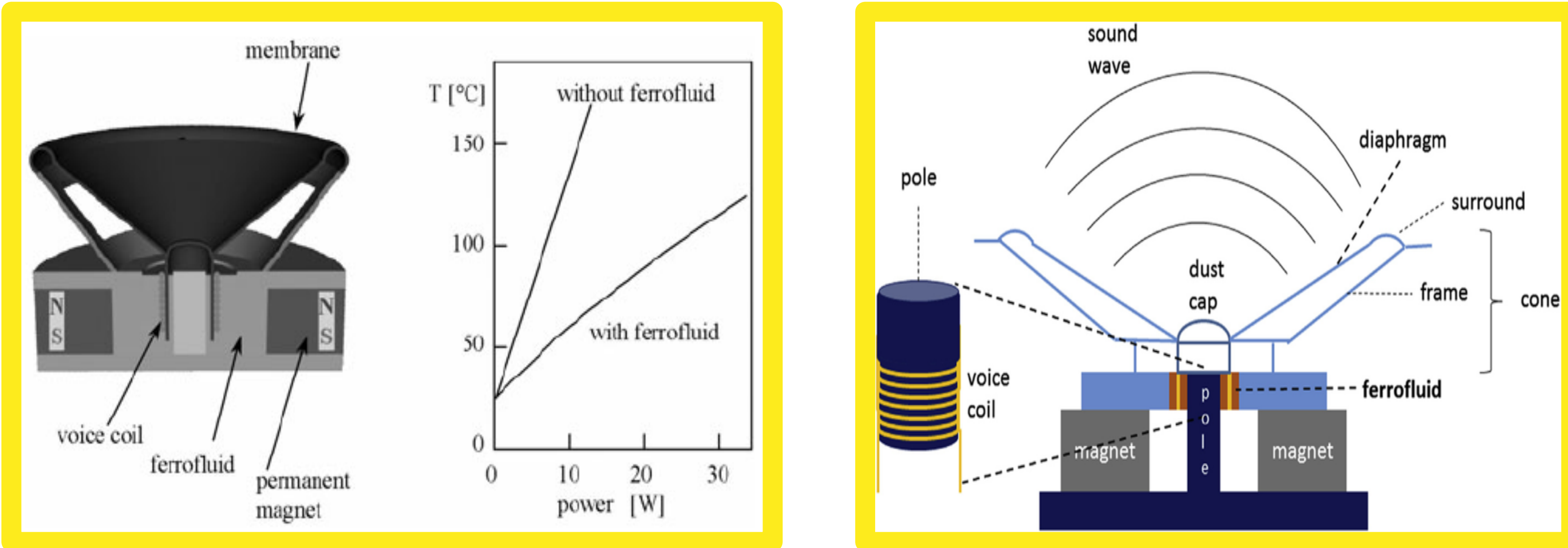


Image 2. Ferrofluids can have very high thermal conductivities and their heat transfer properties are exploited in devices such as loud speakers where they are used to cool the voice coil. In a loudspeaker, sound is produced when the voice coil vibrates but this also generates unwanted heat. Ferrofluids lose their magnetism as they are heated, fully losing their magnetic properties when heated to a high enough temperature. If ferrofluid is placed around the voice coil, a magnet placed near the coil will attract colder ferrofluid than hot ferrofluid because the colder ferrofluid will be more strongly magnetized. This cold ferrofluid will absorb heat around the voice coil and then be moved towards a heat sink as it is replaced by cooler ferrofluid. Image Credit Odenbach, S. (2003). Magnetic fluids - Suspensions of magnetic dipoles and their magnetic control. Journal of Physics-condensed Matter. 15. S1497-S1508. 10.1088/0953-8984/15/15/312.

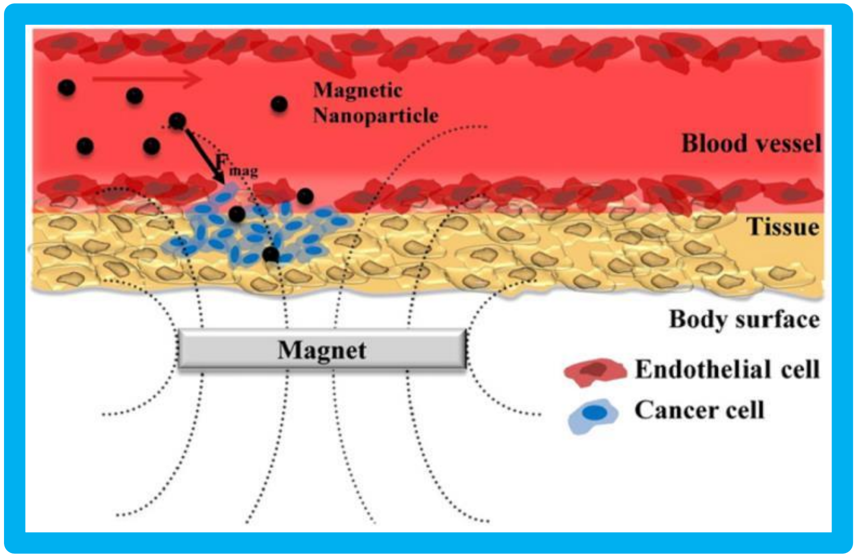


Image 3 Magnetic nanoparticles can be incorporated into polymer microspheres (which are coated with antibodies and/or therapeutic/chemotherapy drugs), injected into tissues and then drawn to the site of a lesion using a strong magnetic field. Image Credit Grillone, Agostina & Ciofani, Gianni. (2017). Magnetic Nanotransducers in Biomedicine. Chemistry - A European Journal. 23. 16109–16114. 10.1002/chem.201703660.

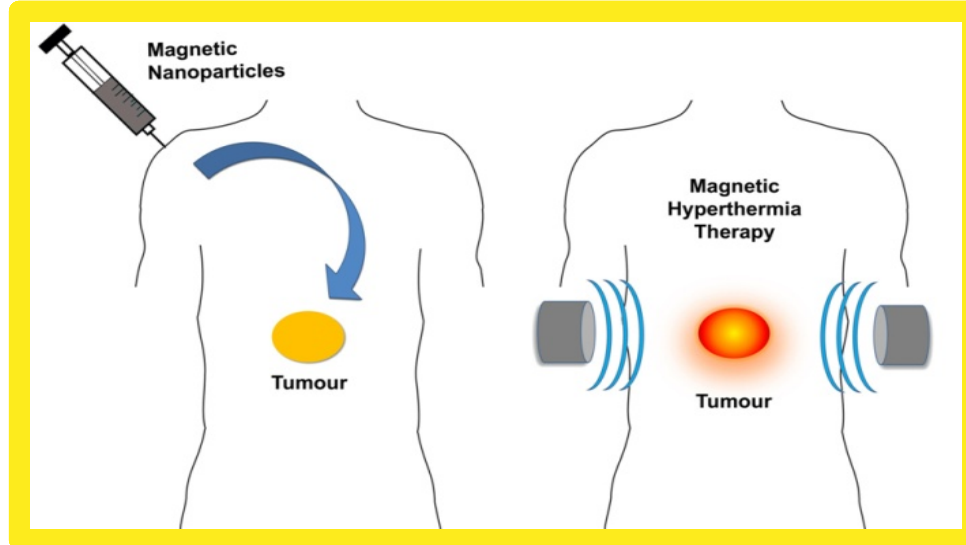


Image 4. General procedure for the endovenous injection of the NMPs suspension into the human body: (a) the particles are first injected in a tumor and, then, (b) an externally applied alternating magnetic field induces the hyperthermia. Image Credit Andrade, A., & Domingues, R. (2011, August 01). Coating Nanomagnetic Particles for Biomedical Applications from https://www.intechopen.com/books/biomedical-engineering-frontiers-and-challenges/coating-nanomagnetic-particles-for-biomedical-applications