Feasibility of Using Magnetic Separation of Oil and Water to Clean Oil Spills

Archit Gupta

McGill University

ABSTRACT

Oil spills are a major cause for concern in water bodies. Economic losses are suffered by the parties and institutions involved while an environmental setback is endured by the regions surrounding a spill. Therefore, it is crucial that any method employed to clean oil spills has a short response time, has little to no environmental effects and is economically viable.

This paper evaluates the feasibility of a new method of cleaning oil spills. This solution falls under the realm of nanotechnology and consists of using magnetic particles to associate with a liquid (either water or oil) and then using magnets to separate the magnetized fluid. A background and methodology is presented. This paper also compares the solution with the presently used methods of skimmers and chemical dispersants and evaluates them against various criteria like efficiency, environmental effects, large scale applications etc. Magnetic separation of oil and water, while a concept still in its infancy, certainly has the potential of being used in operations if the response time is reduced and more insight is gained on the financial aspects.

INTRODUCTION

An oil spill can be one of the worst man-made disasters. According to the U.S. Department of Energy, 1.3 million gallons (4.9 million liters) of petroleum are spilled into U.S. waters from vessels and pipelines in a typical year [1]. While an oil spill is a major concern from an economic and environmental point of view, not much investment is made to support research done for the cleanup part of an oil spill. The response from governments and companies involved is often lackluster after most oil spills. The institutions involved prefer to rely on existing technologies and are not willing to spend resources on developing new ones.

Present methods include using booms to contain an oil spill and skimmers to remove the oil from the accident place. Chemical dispersants are also used to expedite natural biodegradation of oil. Both these methods are widely adopted but they have their drawbacks which are explained further as my research progresses.

In this feasibility report, I am going to analyze a novel solution to clean oil spills which involves magnetic separation of oil and water. I am then going to comment on its feasibility. The method involves depositing magnetic nano or micro particles in oil or water and then using magnets to attract and separate the ferrofluid (a liquid that is magnetized under the influence of a magnetic field) from the other liquid. I will also analyze and compare this solution with present methods of cleaning oil spills. The criteria of comparison shall be efficiency, time required, environmental effects, large scale applications and finance. Although this solution looks promising, improvisations and actual applications are still needed to rationally comment on the feasibility of this method.

BACKGROUND

Oil spills have occurred since the time ships and vessels were used to transport oil. Sinking of a ship, on board accidents, accidental spills, explosion of rigs are some of the major causes of an oil spill [2]. Figure 1 shows the leading causes of oil spill accidents in the last four and a half decades. A spill can have extreme economic and environmental impact, depending on the severity of the accident. The biggest oil spill disaster till date is the British Petroleum (BP) Oil Spill disaster in which hundreds of thousands of oil gallons were discharged each day in the Gulf of Mexico for 4-6 months beginning April, 2010. The spill cost BP a total of 62 billion dollars and caused heavy environmental and economic damage to the states of Texas, Louisiana, Alabama, Florida and Mississippi [3, 4]. In spills of such magnitude, it is crucial to employ clean up technologies which are fast and efficient.

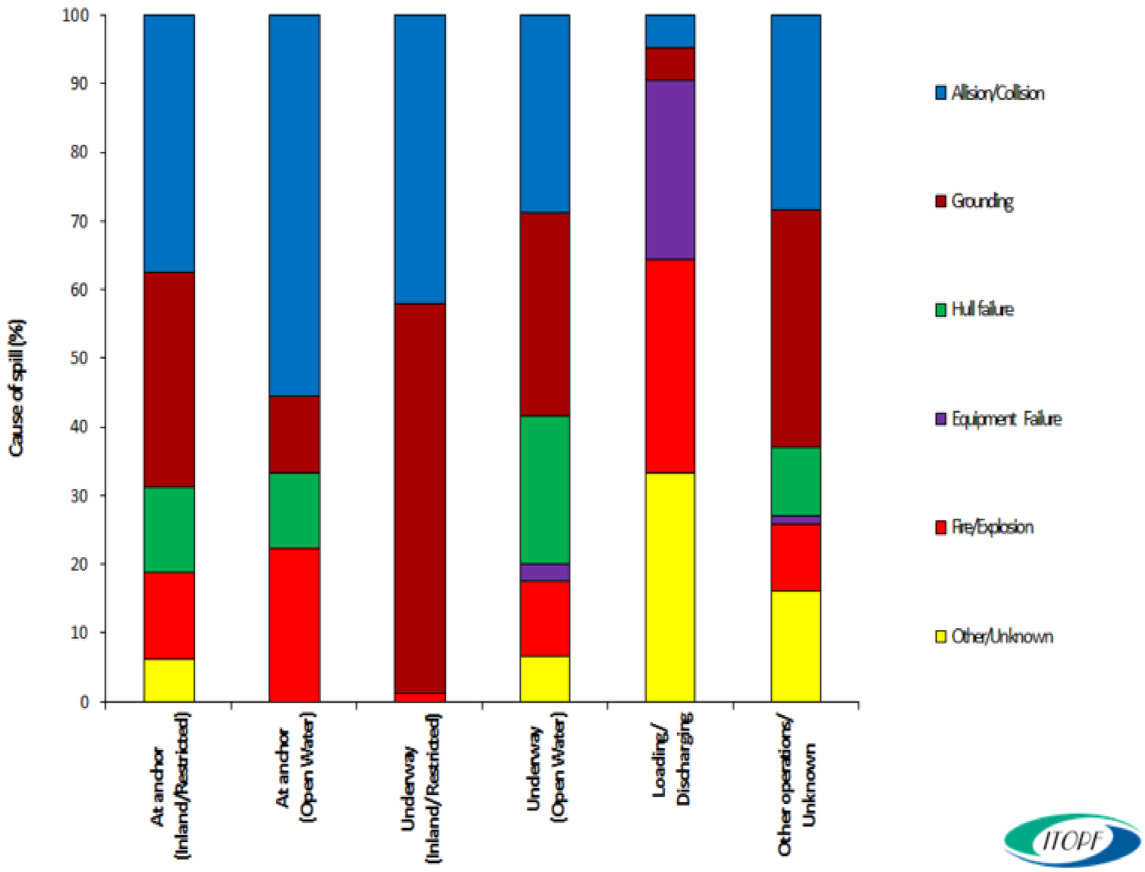

Figure 1: Percentage of causes at different locations. [2].

Presently, there are primarily two methods of cleaning oil spills: skimming and using chemical dispersants. Skimming is a physical technique in which oil skimmers are used to separate the top layer of oil from the water. A boom is used which is a large circular inflatable tube deposited around the spill in order to contain it [5]. The boom concentrates the quantity of oil in its region, thereby rendering skimmers more effective [5]. Skimming is effective in spills where the oil remains on the top and is primarily of a single density. But it is largely ineffective in choppy waters or in spills where the accident involves oils of different densities which does not result in a uniform layer of spilt oil, but rather a multilayer cross-section with the lighter oils on the surface of water and the denser oils beneath the surface. Also, in inclement weather and high winds, the oil can easily jump over the boom, thereby reducing its effectiveness [12]. While skimming does not score high on efficiency, it is a cheap and time saving method as it is extremely easy to employ.

Chemical dispersant, while a widely used substance to break down oil into droplets for ease of aquatic integration and thereby speedier natural biodegradation, have largely harmful effects on marine life. Dispersants consist of emulsifiers and solvents which break down oil into smaller droplets. These droplets go deep into the ocean, as was the intent, but in the process, are detrimental to in-sea life. Using chemical dispersants is a fairly effective method, but is an extremely perilous one for aquatic life.

The method I am proposing in my feasibility report falls under the realm of nanotechnology. The objective is to magnetically separate oil and water and the principle is that a ferrofluid flows normally when there is no magnetic field but is attracted to the field under the influence of one.

This method was developed by Shahriar Khushrushahi, a then post-doc student at MIT's Department of Electrical Engineering along with Markus Zahn and Alan Hatton, both professors at MIT. Briefly put, the method includes dipping magnetic particles in oil or water. This makes either of those fluids a ferrofluid, a fluid attracted by magnets. The next step is to make this ferrofluid, which is still a part of the oil-water mixture flow perpendicularly to cylindrical magnets. This causes the ferrofluid to cling to the magnets while the other liquid keeps flowing beneath. This process takes place aboard a vessel or on a temporary land facility. It can even be classified as a 'refinement' process as the percentage of oil recovered is much greater than in the traditional methods [6].

CRITERIA

The following criteria need to be considered to establish if this solution is feasible or not. The criteria are listed in order of precedence.

1. Efficiency: The method used should be efficient at least to a level to justify the costs of all the money, resources and time being poured in to clean oil spills. Efficiency refers to the degree of offsetting the harms done by an oil spill. If the proposed method restores the environmental damage done but costs a lot of money, it may not be very rational to implement that solution.

   → Response Time: Time is an important factor while considering oil spill clean ups. If the proposed method takes a lot of time to complete, it may not be the best solution. As time elapses, it becomes more difficult to separate the oil from the water. Environmental effects are also increased as the spill expands its scope continually with time.

2. Environmental Effects: The recommended solution should be environment friendly as it wouldn't be logical to employ a method which is just adding to the environmental stress caused by the oil spill.

3. Large-Scale Applications: The proposed method should be able to clean up large scale oil spill incidents and not just those in labs or self-generated small scale oil spills (which are done for testing purposes).

4. Finance: An oil spill is a disaster which involves huge financial implications. The BP oil spill caused British Petroleum 62 billion dollars in losses, insurance claims, clean-up costs, damages, penalties and many other heads [3]. The method used in oil spill cleanups should be financially viable so that the company is willing to employ it.

DISCUSSION

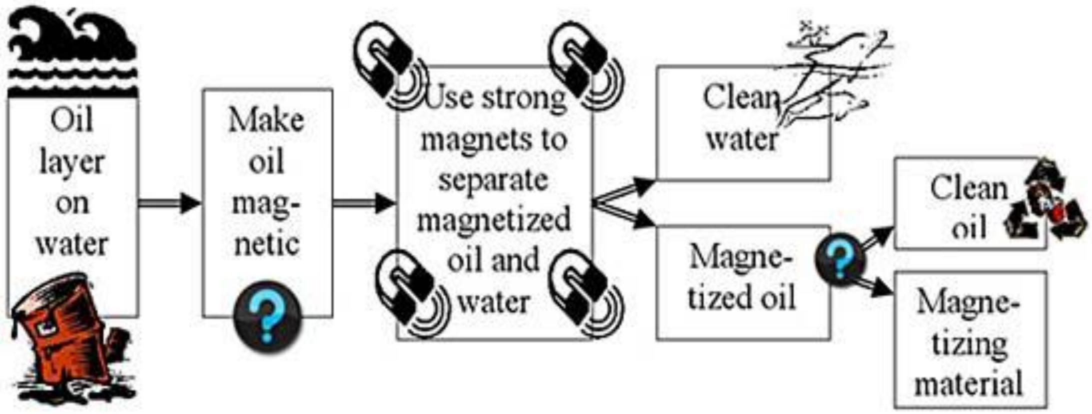

Figure 2. Flow chart visualizing the proposed procedure to separate oil (spills) from water using magnets by first making the oil "magnetic." [7].

I am now going to give a brief overview of the methodology and then compare this solution with the existing ones.

<u>Methodology:</u>

<u>1ST Step: Adding the nanoparticles (Magnetizing)</u>

The aim of this step is to create a suspended mixture in which the magnetic particles present may be hydrophilic or oleophilic [8]. It is important that the magnetic particles be of the order nano, micro or bigger. If the order is smaller, the magnetic particles (with the oil or water) may not be attracted to the magnets, which will be done in the second step. Some choices for the materials of the magnetic particles are iron, cobalt, chromium, manganese and alkaline earth metals [8]. These particles can be added to the oil or the water via physical means such as a mixer or using alternating magnetic fields. There are primarily 3 methods to do this step:

- ➔ Addition of the nanoparticles (10^{-9}m) will create a colloid which will be stable in the oil phase or in the water phase [8]. This is done in a controlled environment to get a uniform density of the entire mixture. Depending upon the size of the magnetic nanoparticles and its magnetic properties, LIMS (Low Intensity Magnetic Separator), WHIMS (Wet High Intensity Magnetic Separator), HGMS (High Gradient Magnetic Separator) can be used for the eventual separation i.e. the second step [8].
- ➔ In this method, micro particles (10^{-6}m) are used [8]. This gives the particles a relatively larger area for clinging to the oil or the water, depending on whether the particle is oleophilic or hydrophobic. Surfactants make this selective attraction possible [8].
- ➔ The third method is to add particles in order to create a Pickering emulsion [8]. In a Pickering emulsion, the added particles (in this case magnetic nano/micro particles) deposit themselves in the interphase between the two liquids (in this case oil and water). This doesn't let the oil droplets coalesce, leading to a more stable solution.

2nd Step: Separating the magnetized fluid

This is the second and final step. It involves the separation of the magnetized fluid from the non-magnetized one. Simple existing technologies and using the concept of magnetic fields attracting magnetized materials make this step possible. The separation can even be achieved by using a Halbach array. A Halbach array is a special arrangement of magnets which gives a strong magnetic field on the array side and a field with a near 0 magnitude on the other side [9]. Magnetic poles are kept in a rotating pattern which makes the magnetized fluid shift towards the array side [11]. A typical Halbach array has a magnetic field which is two times stronger on the side where the magnetic flux is confined [11].

Once the magnetized fluid is retrieved, the magnetic field can be applied again to collect the magnetic particles leaving behind the pure fluid [8]. Finally, the oil can be sent to containment facilities, the water can be discharged back into the ocean and the magnetic particles can be used again for a similar process or recovery [8].

Comparison:

As far as efficiency is concerned, this method scores much more than the method of using skimmers or chemical dispersants. In this solution, a refinement factor is present which gives us a good percentage of oil recovered. This method is also environment friendly as it does not release any harmful materials into the ocean as does the method of chemical dispersants. But is it not eco-friendlier than using skimmers as the latter is purely a physical method while magnetic particles can become an issue if not disposed of properly. An approximation needs to be done of the finances involved with this method but the cost will definitely be higher than just using booms and skimmers.

A perfunctory glance at the table below shows that currently, using skimmers might be the best way to clean oil spills. But this method (using magnetic particles) might hold a lot of potential if used in conjunction with the other two.

Efficiency	Magnetic Nanoparticles > Chemical Dispersants > Skimmers
Environment Friendly	Skimmers > Magnetic Nanoparticles > Chemical Dispersants
Time	Skimmers > Magnetic Nanoparticles > Chemical Dispersants
Large Scale Applications	Skimmers = Chemical Dispersants > Magnetic Nanoparticles
Finance	Skimmers > Magnetic Nanoparticles = Chemical Dispersants

TABLE 1: Comparing the three methods against the criteria explained above

CONCLUSIONS AND RECOMMENDATIONS

The magnetic method has been very successful in lab conditions but it hasn’t been tested in real life oil spills. Conditions which are hard to emulate in a lab are inclement weather (which has a high chance of occurrence given that most oil spills take place in oceans and large water bodies) and time constraints (swift response is crucial in an oil spill). Also, substantial use of oil inside a lab for testing purposes is virtually impossible. Hence, large scale application is a major impediment for use of this method. As this involves magnetic separation after collecting the oil-water mixture from the sea using booms and skimmers, the time needed is always going to be more than the conventional method of just using booms and skimmers. "On a small-scale it (the magnetic technique) may be an excellent system but I don't think it will work at sea in such a challenging environment," says Dr Susan Shaw, founder of the Marine Environmental Research Institute [10]. I concur to a high degree with Dr Shaw’s conclusion.

The efficiency of this method is immensely improved over the traditional skimmer method as the oil is meticulously separated using a new technology rather than a physical process. More studies need to be done on the effects of magnetic particle contamination on the environment along with making financial approximations in order to rationally judge the feasibility of this solution.

WORKS CITED

[1] Andrea Thompson. (2010, April 23). *FAQ: The Science and History of Oil Spills* [Online]. Available: http://www.livescience.com/9885-faq-science-history-oil-spills.html

[2] *Oil Tanker Spill Statistics* [Online]. Available: http://www.itopf.com/knowledge-resources/data-statistics/statistics/

[3] The Associated Press. (2016, July 15). *2010 Gulf oil spill cost BP $61.6 billion, company reports* [Online]. Available: http://www.al.com/news/index.ssf/2016/07/2010_gulf_oil_spill_cost_bp_61.html

[4] 11 Facts about the BP Oil Spill [Online]. Available: https://www.dosomething.org/facts/11-facts-about-bp-oil-spill

[5] Denise Chow. (2010, April 5), How are Oil Spills Cleaned [Online]. Available: http://www.livescience.com/32524-how-are-oil-spills-cleaned.html

[6] Larry Hardesty, "How to Clean Up Oil Spills," MIT News Office, September 12, 2012

[7] Sabine De Brabandere, PhD, Science Buddies**.** *Facilitator/Educator Guide: Can Nanotechnology Help Clean Up Oil Spills in Oceans and Seas? Try It Yourself with Ferrofluid* [Online]. Available: http://www.sciencebuddies.org/science-fair-projects/Classroom_Activity_Educator_CleanUpSpills.shtml

[8] Markus Zahn et al (3), "Magnetic Colloid Petroleum Oil Spill Clean Up of Ocean Surface, Depth and Shore Regions", US Patent No. 13/369,338, August 23, 2012.

[9] *Halbach Arrays* [Online]. Available: https://www.kjmagnetics.com/blog.asp?p=halbach-arrays

[10] Tom Levitt. (2012, September 21). *Cleaning up oil spills with magnets and nanotechnology* [Online]. Available: http://www.cnn.com/2012/09/21/tech/oil-spill-magnets/

[11] Y. Ijiri et al, "Inverted Linear Halbach Array for Separation of Magnetic Nanoparticles", IEEE Trans Magn., July 2013.

[12] Office of Response and Restoration. (June 17, 2015). *How do Oil Spills Out at Sea Typically get Cleaned Up* [Online]. Available: http://response.restoration.noaa.gov/about/media/how-do-oil-spills-out-sea-typically-get-cleaned.html