Study of Ferrofluid and Magnetic Fields

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Abstract

Ferrofluid is a new type of functional material, which has the fluidity of a liquid and the magnetism of solid magnetic material at the same time. The colloidal liquid is formed by mixing micro-nanomagnetic particles, surfactant, and a carrier liquid. This report discusses the methods and processes of preparing ferrofluids and compares the advantages and disadvantages of various ferrofluid preparation methods. Besides, with the chemical coprecipitation method, the dilution pH value and rate of the dropping ammonia water are also changed. It is intended to establish a set of standard diluted ammonia water pH value scales and to explore its impact on yields.

In this study, a low-cost self-made magnetic measuring device was used to measure the magnetic force of different magnets and different angles and positions. Also, its measured values were used to draw multiple charts for analysis. From the process of studying the magnetic field, it is also found that ferrofluid will produce cones similar to Taylor cones when attracted by magnets. To get this project done, we set up self-made observation equipment and observe the influence of various variables on the behavior of cones. Meanwhile, data analysis of cones is done.

Keywords
Ferrofluid, Magnetic field, Chemistry, Chemical coprecipitation method.

1. Introduction

With the development of modern science and technology, while pursuing the convenience of life in the future, environmental protection of energy and pollution reduction are the primary projects of scientific research. The efficiency of using ferrofluid power generation technology is astonishing 60%. Compared with thermal and nuclear power generation, there is less concern about the environmental and human hazards. Ferrofluid can also be used in medical treatment, using nanoparticle magnetic induction hyperthermia technology to treat cancer. This multifunctional material will be widely used in the future, but how to use ferrofluid more effectively, the detection material will be an important topic. This research hopes to find a low-cost and high-precision experimental method to measure the various values of ferrofluid, and at the same time to study a high-yield ferrofluid manufacturing method, reduce waste generation, and try to protect the global environment.

1.1 Objectives

The preparation methods and processes of various ferrofluid are studied, and the integrated analysis is carried out by exploring the materials and processes for the production of ferrofluid. The effects of ammonia water drip rate and pH on iron oxide generation in ferrofluid were discussed.

The magnetic sensing device equipment is made by Arduino element, and the numerical size and distribution space of the magnetic field are studied, and the three-dimensional pattern is used to visualize it.

Discuss the appearance and uptake reaction time of the cone produced by the ferrofluid of different production variables under the action of the magnetic field of the magnet. Data analysis of the ferrofluid generated cone film will be conducted to extract information on trajectory.

2. Literature Review

The following compares various ferrofluid production methods from the literature. Find a low cost and low pollution method. Table 1 compares various ferrofluid manufacturing methods. Based on the above conditions, the chemical coprecipitation method is finally selected for in-depth discussion.

Table 1. Ferrofluid Manufacturing Method.

Production method	Advantage	Disadvantage
Chemical coprecipitation method	There are many experimental variables, which increase the flexibility of the experiment.	No obvious shortcomings.
Decollide method	The experimental procedure is simple.	It is only suitable for the production of ferrofluid of Nonaqueous Phase Liquid.
Comminution process	Handed over to machine production, reducing manpower expenditure.	The mechanical crusher is difficult to obtain.
Hydrothermal synthesis	Makes indissolvable substances react.	The autoclave kettle is difficult to obtain.
Electroerosion spark discharge precess	Can produce stable ferrofluid.	The use of electricity increases the risk of experiments.
Electrophoresis method		
Grinding method	Direct and simple method.	It is impossible to produce nano-level ultrafine particles.
Thermal decomposition method	The experimental procedure is simple.	It is difficult to obtain ultra-high temperature heating equipment.
Evaporation and sputtering	The resulting iron powder has fine particles.	It is difficult to create an oxygen-free vacuum space.
Carbon powder	The production method is simple.	The experimental variability is low, and only carbon powder containing iron oxide is required.
Anion Exchange	Can produce stable magnetic ferrofluid.	The resin may dissolve organic matter.
Ultraviolet photoelectron spectroscopy	High-energy light can produce ultrafine particles.	Strong light emitters are not easy to obtain.
Hydrogen reduction reaction	The experiment has a high success rate.	Limited to gas-solid reaction.

The chemical coprecipitation method :
0.25M 8mL $FeSO_{4\ (aq)}$ is evenly mixed with 0.25M 16mL $FeCl_{3\ (aq)}$. Drop 0.5M 50mL $NH_4OH_{\ (aq)}$ in the mixed , aqueous solution and stir until Fe_3O_4 is generated. Using magnets, deionized water purifies Fe_3O_4, to pour out the excess waste liquid. Drop in the interface active agent 2mL oleic acid stir evenly. Add the carrier 4mL ethyl acetate to mix evenly and ferrofluid production is complete.

3. Methods

On the initial stage, ferrofluid could not be made successfully with the a chemical coprecipitation method. After examining the various experimental steps, it found is that the diluted ammonia water added to the drop is is essential to the process. The effects of titration rate and dilution of pH on the generation of ferromagnetic particles (troglodytic iron oxide) in ferrofluid are discussed below. Dilution of the pH of the dripping ammonia water to too low can result in the inability to produce black and magnetic iron oxide, but instead it produces brown iron trioxide, which is not magnetic. A magnetic ferrofluid cannot be produced using iron trioxide. Therefore, we hope to observe the production of iron oxide by controlling the concentration of ammonia and speculate on the causes of its phenomenon. The following is undiluted ammonia (25%) used to mix with the diluted water solution. Dilute 0.5/1/2/4/8/16/32 mL ammonia to a total volume of 50mL, respectively. Use a pH meter to measure the pH of the diluted ammonia solution. The diluted water solution was dripped into different cups of the iron salt mixture and the results were observed. In this way, we find out the lower bound of ammonia pH which can produce iron oxide, and make a drop quantitative table.

To observe the behavior of ferrofluid at different magnetic field strengths, a simple magnetic sensing device is made to visualize the distribution of magnetic fields in space. Attempts were made to measure the magnetic field horizontally and vertically. Using the Arduino analogy Hall magnetic sensing module, a magnetic measuring ruler is made, so that the sensing module is fixed, and the magnetic value of each 0.5 zenith adjustment of the magnet is observed and recorded. The rectangular back plate four feet glued to Lego, used to pad the high-pressure her body plate to keep the magnetic sensor away from the desktop, to avoid magnetic sensor readings by other factors interference. Label either side of the magnet to identify the positive and negative, but place the magnet back and forth, so that the magnetic line through the direction of the sensor changes, but in the meantime the sensor overall positive and negative position also changes, and observe the magnetic field reading results. Build a homemade magnetic sensing device, using Arduino analog Hall magnetic sensing module (for the generation Gauss meter) to measure four times four cents (and twenty-five points) of grid paper, measuring the intersection of grid paper instead of the more difficult plane No dead-angle magnetic field measurement, after the plane measurement is completed, and then at every 0.95 cent-cent LEGO plus device , the height is 0.75 cent-cent- and the height-up plane is re-measured. Finally, a three-dimensional map of the magnetic field is drawn using the magnetic data that measured each plane. The initial first layer of stacked LEGO is 1.7cm high, then one layer per 0.95cm LEGO layer up , and the magnetic value is measured.The following is a three-dimensional map of the magnetic field, with one centigram of the length of each grid segment and a magnetic numerical record sheet attached. The magnet is located directly above the station (0,0). The method described above is shown in the Figure 1 below, which is a design drawing of a magnetic sensing device

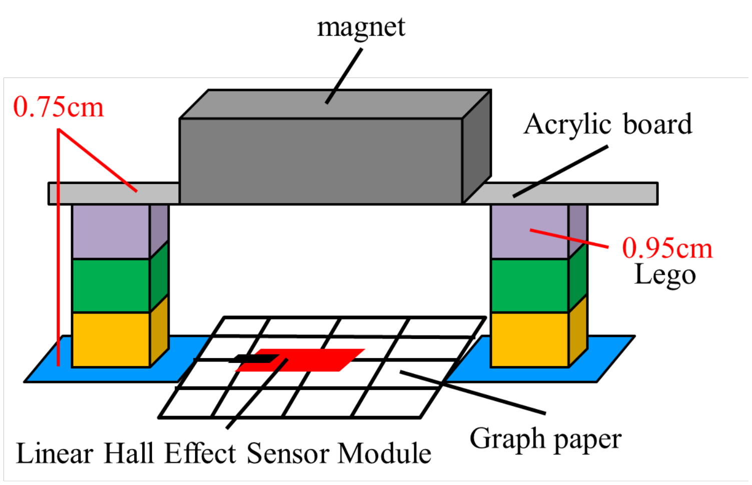


Figure 1: Schematic diagram of magnetic sensing device.

Often in the manipulation of ferrofluid, people are used to using magnets placed under the fluid sliding manipulation; however, this study will place magnets above the fluid to attract. When the magnet is separated from the ferrofluid, the ferrofluid is sucked up a Taylor-like cone, which is absorbed from the liquid surface and attached to the magnet when the one forms up to a critical height. Below is a device that observes ferrofluid attracted by magnets to produce a Taylor cone. Use corrugated plates to prevent magnetic fluids from adsorbing directly to magnets without interfering with magnetic field strength. By placing the scale, we can observe the individual mass of each cone forming and disengaged from the liquid surface. Explore the individual time 10 drops before the formation and break out of the liquid surface to the top magnet to produce a cone shape like a Taylor cone. The experimental steps to explore the causes of the production were improved according to the chemical coprecipitation method, and after drying trioxide at the point, the quality of iron oxide powder, the type of interface active agent, the type of fluid carrier, and the strength of the magnetic field (the height of the LEGO structure) were changed. The dosing of the above drugs is based on the degree of dispersion and uniformity of the stirring at the time of production. Interface active agent oleic acid and liquid olive oil and ethyl acetate are reference recommended drugs. Triton X-100 is a trial drug but also an interface active agent. In this Picture 2, through many experiments, it was found that a cone that is extremely similar to a Taylor cone is formed, which can be used to help calculate the various values of ferromagnetic fluid.

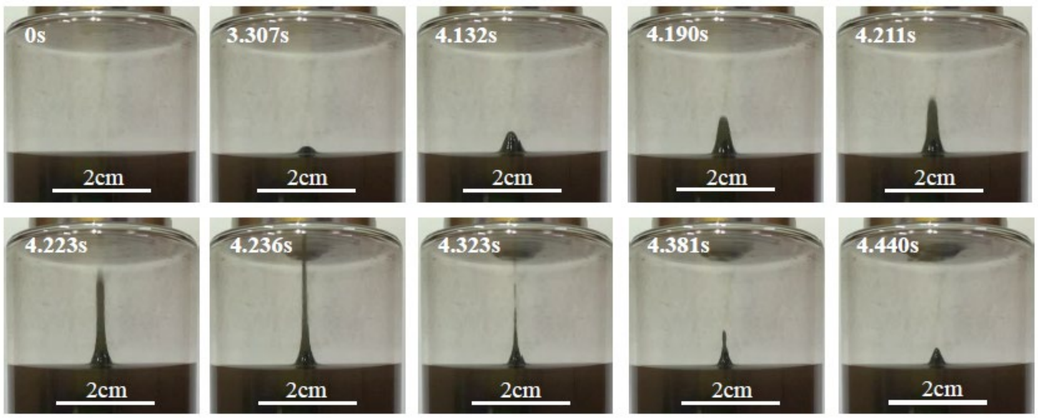


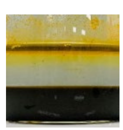
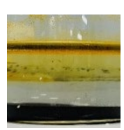
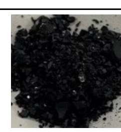
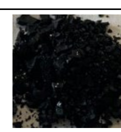
Figure 2: Ferrofluid cone production diagram.

The film was made by observing ferrofluid like a Taylor cone device, and the finished film was placed into the Tracker software for analysis. Let three points mass to track the vertex of a Taylor cone, the bottom left corner of the liquid surface, and the lower right corner of the liquid surface, to record the movement of the cone per frame in the movie.

4. Data Collection

The pH value experiment results of the chemical coprecipitation method are shown in this Table 2.

Table 2. Ammonia water pH value table.

ammonia water (mL)	0.5	1	2	4	8	16	32
pH	11.20	11.46	11.71	12.09	12.47	12.83	13.12
Product after dripping ammonia water							
Purify and remove moisture	-	-					
weight (g)	-	-	0.452	0.449	0.503	0.476	0.453
yield *	-	-	47.4 %	47.1 %	52.8 %	49.9 %	47.5 %

yield * : Purely calculate the yield of iron mixture.

The measurement results of the self-made magnetic induction device are in Table 3.

Table 3. Magnetic value (gauss).

	-2	-1	0	1	2
-2	227.36	270.48	268.52	235.20	203.84
-1	280.28	297.92	299.88	276.36	231.28
0	276.36	307.72	307.72	282.24	233.24
1	258.72	274.40	280.28	254.80	199.92
2	205.80	233.24	225.40	196.00	152.88

Draw this Figure 3 of the measured values of the self-made magnetic induction device.

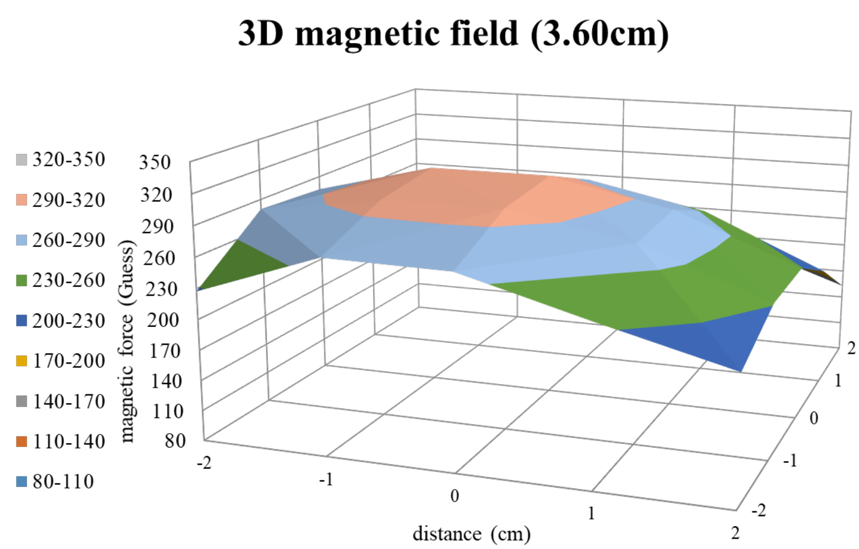


Figure 3: 3D magnetic field.

The formation time of the ferrofluid cone formed by changing different carrier fluids is recorded in Figure 4.

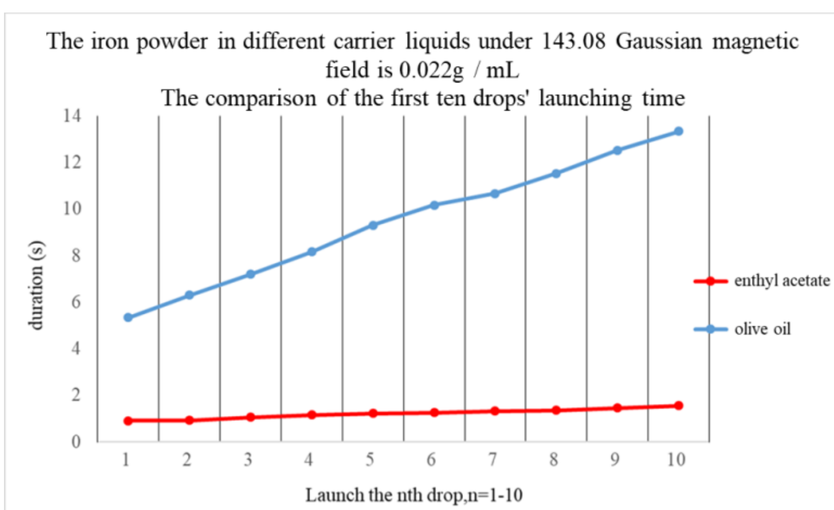


Figure 4: Ferrofluid carrier fluid comparison.

The experimental photos of ferrofluid cones formed by changing different carrier fluids are recorded in Figure 5.

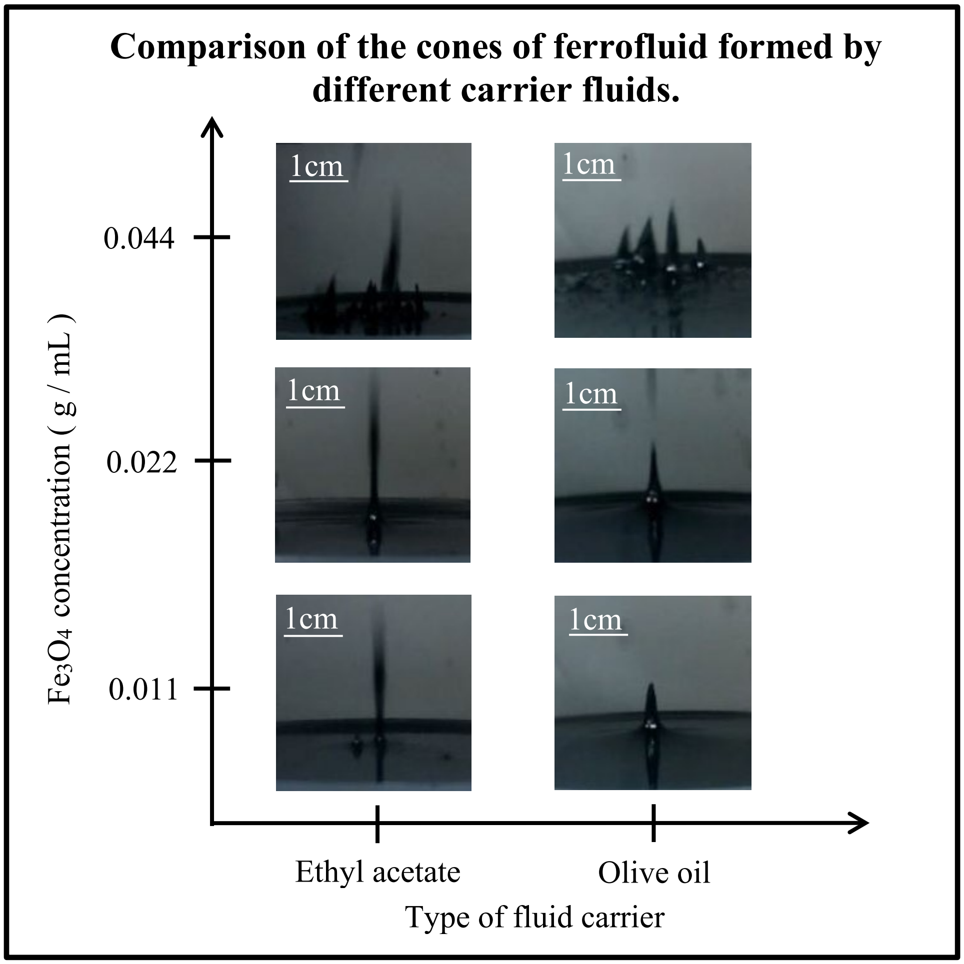


Figure 5: Comparison of the cones of ferrofluid formed by different carrier fluids.

In Figure 6, the outer profile of the ferrofluid cone is drawn using tracker and compared with the Taylor cone in the literature.

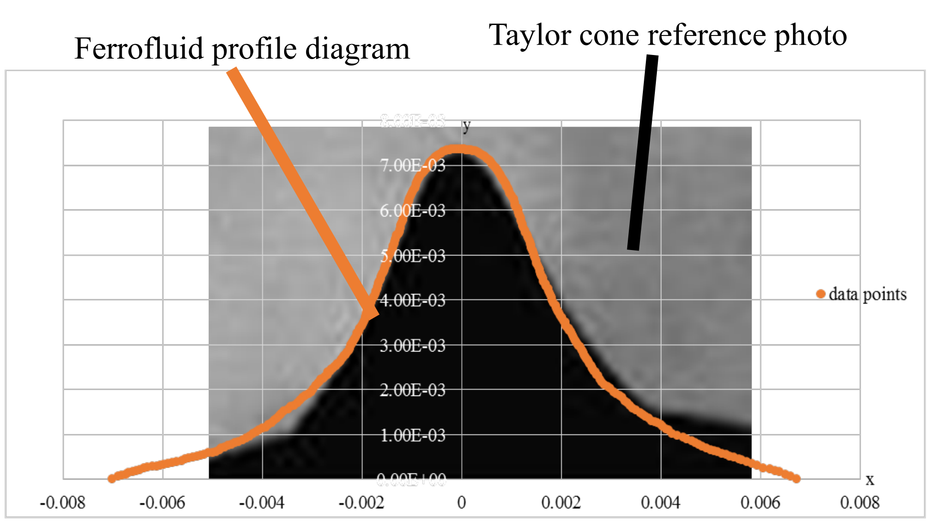


Figure 6: Similarity between ferrofluid cone and Taylor cone.

Since the horizontal displacement of the cone is almost stationary, the displacement, vertical velocity, and vertical acceleration of the cone are calculated and recorded in the Figure 7, 8, 9 below.

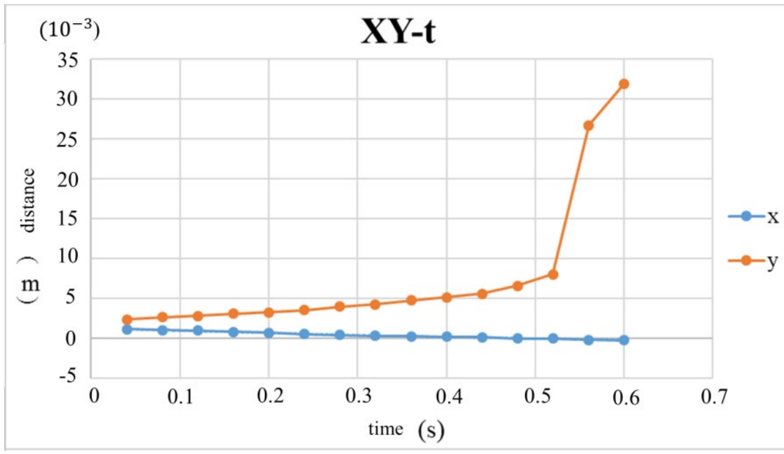


Figure 7: Tracking cone XY-t diagram.

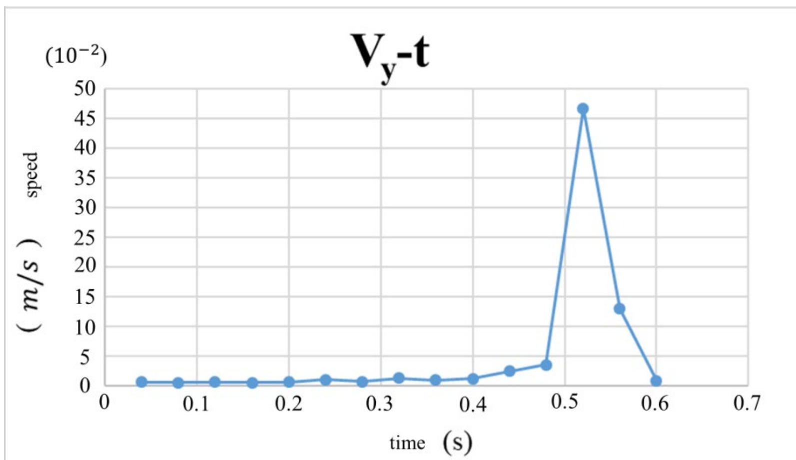


Figure 8: Tracking cone V_y-t diagram.

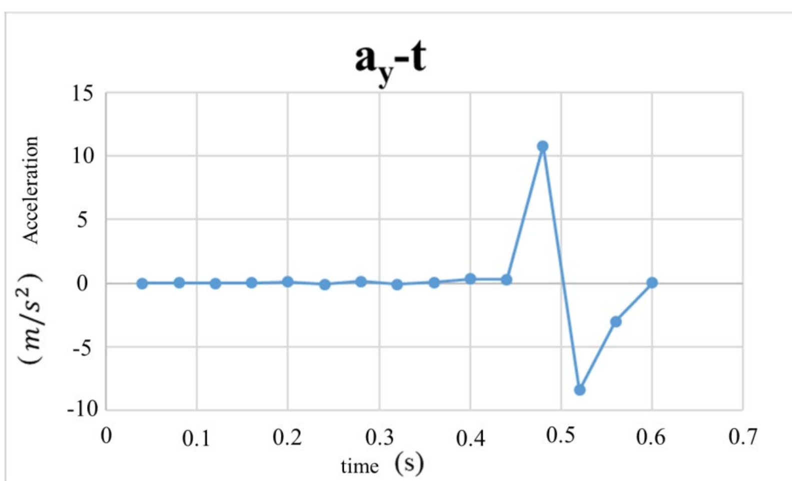


Figure 9: Tracking cone a_y-t diagram.

5. Results and Discussion

5.1 Numerical Results

In this study, it is concluded that the reason for the generation of iron oxide in different states at different pH values is that the rate of iron oxide generation in different states is different in the same pH. For example too high a pH reaction environment to generate stable iron trioxide faster, the pH interval in this study to generate iron trioxide faster, lower pH to generate iron trioxide or iron hydroxide faster, resulting in iron trioxide which can not be generated. The pH value of the diluted ammonia water is between 11.71 and 12.83 to produce ferroferric oxide, and the pH value of 12.47 produces a higher yield of magnetic materials.

5.2 Graphical Results

According to the above chart numerical records and magnetic 3D spatial mapping, it is found that the farther away from the magnet from the sensing module, the greater the decrease in the magnetic intensity value. The center of the grid paper (0,0) is the position directly below the magnet and is also the strongest position for magnetic field values in space. This experiment has used a simple method to establish a set of magnetic wire rulers that can be used as the basis for the next stage of magnetic research for quantitative analysis, which can replace the magnetic distribution measuring device of the current commercially available FE-2100R surface magnetic field distribution measurement device.

According to the above experiments, it is found that the concentration of ferroferric oxide is 0.022g/mL, the surfactant is oleic acid, and the carrier liquid is olive oil, which best meets the objective of this experiment to observe the cone. In the three-dimensional magnetic field map drawn by the perpendicular magnetic force measurement, it can be observed that the magnetic field strength in the center of the magnet is stronger, and it is also reflected in the ferrofluid-like Taylor cone outer shape, where the strong magnetic force protrudes and then attracts upwards. On the magnet.

After superimposing the two pictures, it can be observed that the shapes are almost identical. About the cone shape curve of the Taylor cone, it should be an exponential function. I hope that this part can be improved with calculus calculation in the future.

According to the cone XY-t diagram, it can be observed that the cone will accelerate rapidly when it leaves the liquid surface.

5.3 Proposed Improvements

A study similar to the Taylor Cone, presents novel arguments. It is expected that in the future it will be expected to use surface equations or other mathematical theories to shape the cone, using software to calculate the boundary position and critical time of the cone from formation to disengagement. At the same time, the data are fitted in the emission time comparison graph of different variants as those drawn in the Taylor Cone study, the relationship equations are found and the experiments are compared. The equation is calculated to be compared to the Taylor cone equation in electrostatic spinning.

5.4 Validation

In order to test the accuracy of the self-made magnetic sensing device used in this experiment, the magnetic measurement values are sorted in Table 4 and substituted into the Helmholtz coil formula for calculation.

Table 4. Sensor measurement result of Helmholtz coil.

	first time	second time	third time	average
Magnetic field value (gauss)	19.6	19.6	19.6	19.6

Theoretical calculation:

$$B = \frac{\mu_0 I R^2}{2(R^2 + z^2)^{3/2}} = \frac{4\pi \times 10^{-7} \times 2 \times 0.1^2}{2(0.1^2 + 0.14^2)^{3/2}} = 19.3 \text{ G}$$

Error value= $\left| \frac{19.6 - 19.3458801}{19.3458801} \right| \times 100\%$ =1.3 %

6. Conclusion

Through practical experience and access to a variety of reference materials, it is considered that the chemical coprecipitation method is the most suitable method of production for experimental exploration. The reason is that in addition to the low requirements of experimental equipment, there are a variety of variables that can be changed, increasing the experimental nature of the scheme.

This study points out that the pH of ammonia is a key factor in the preparation of ferrofluid, and speculates that the hypothyroidism of the pH of 11.35 to 11.52 can produce black and magnetic trioxide. Using the above experimental results, a table of pH of dripped ammonia water was made.

To observe the behavior of ferrofluid under the magnetic field, this study made a low-cost magnetic sensing device, which replaced the Gauss meter with Arduino analog Hall magnetic sensing module, and lego replaced the optical platform set-up device. If the above equipment is corrected, the error value is very small.

This study jumps away from the traditional magnet close to the bottom of the ferrofluid to observe its appearance changes, but the magnet is placed above the ferrofluid, ferrofluid surface by the magnetic field of the strongest one to be sucked into a cone, until the cone is attracted to a certain height by magnetic force, and then the taper is absorbed from the liquid surface to the magnet. Because the cone produced by the above behavior is similar to the Taylor cone in electrotechnical spinning, it is named like the Taylor cone.

To observe the influence of changing the production variable of ferrofluid on the uptake reaction of Taylor cone-like, some experiments were carried out, and the graphs of the formation of the outer shape of the cone and the time for the first ten drops to be emitted to the surface of the magnet were organized. In the experimental conditions of this study, when the ferrofluid Fe3O4 iron powder concentration is 0.022g/mL, oleic acid 10mL, olive oil 35mL, and the magnet is separated from five layers of Lego (magnetic field strength 143.08G), the resulting Taylor cone is Better to observe and analyze phenomena.

At this stage, the Tracker software has been used to initially analyze the movement trajectory of the cone, calculate the angle tangent between the cone tip and the two particles close to the liquid surface, and observe the movement of the vertebral body. In the future, I hope to analyze the influence of magnetism and gravity on the motion of Taylor-like cones.

In addition to sound literature collection, by modulation of various pH ammonia drips, this study reveals that the chemical co-sinking method can successfully generate the conditions of trioxide and collated into a table, the above data successfully solved in the production of ferrofluid may have problems, successfully overcome the literature did not mention the reproduction conditions, the future will be pH more subdivided so that the table more accurate.

This study used LEGO, Arduino components, etc. to create a cheap and easy-to-access a magnetic field detection device, although the function can not fully up to standard, the 3D mapping of magnetic field can be compared with commercial machines. In the future, it is hoped that additional functions will be added to the magnetic field measurement component to develop a device that can replace commercially available machines at a low price.

Also, this research puts forward the innovative theory of ferrofluid-like Taylor cone. The research report provides pre-work for future calculations of ferrofluid-like Taylor cone simulation equations, critical positions, and critical times. In the future, the above data will be calculated through program software and compiled into a more complete research report.

In this study, by comparing the production methods of ferrofluid in the literature, the chemical coprecipitation method with lower pollution was selected for research. Research the chemical coprecipitation method to find out the key to the production of pH, and develop high-yield experimental methods to reduce waste. Then I invented a low-cost and high-precision method for detecting the value of ferrofluid and found that the ferrofluid resembles a Taylor cone. This cone is convenient to calculate the value, and successfully calculates the displacement, velocity, and acceleration of the ferrofluid. Hope in the future Can calculate density, viscosity, fluid mechanics, and other calculations. While using such multifunctional materials, greatly reduces unnecessary waste of resources and achieves the goal of low pollution that modern science is pursuing.

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Biography

LI,LAN-CHENG lives in Chinese Taipei and is now studying in the gifted class of Yongchun Middle School. Won many awards in high school student research competitions, such as the Macronix Science Awards, known as the Nobel Prize for high school students, and the opportunity to participate in TISF in 2020. Is a high school student who loves research.

LI,I-KAI is from Yongchun High School. I like to study things related to science and do experiments by hand. With curiosity in the special research process, the winning competitions in the submission competition include Zhengxiu University of Science and Technology 2020 National High School Vocational School Special Production Competition, National Senior Middle School Essay Writing Competition, 109 Senior Middle School Green Chemistry Creative Competition, The 109 Annual Meeting of the Chinese Society for Materials Science, the 109 Annual Meeting of the Chinese Society for Materials Science, the 8th MRT Cup High School Inter-School Papers and Special Publications Selection Meeting