DETERMINING THE EFFICIENCY OF INK BY MANIPULATING THE EFFECT OF VISCOSITY

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Abstract –

The purpose and use of ink is widely used in all sectors of the world. Primarily, the most prominent use of ink is displayed in the education sector usage of students and professors. As they flow the nib of the pen on the sheet of paper, the roller in the nib releases ink from the refill and lets them write smoothly. When people age, they have used thousands of pens until their graduation. But sometimes they prefer to stick with one pen that fits their writing style and speed. This is because of the fact that different ink companies have different sets of ink densities and viscosities that make the ink of each different pen unique. The identity of a pen is made by how that pen performs, and this is looked after by the silent feature of the composition of viscosity of the ink. I, myself, set out an experiment on the effect of gliding and writing properties of ink by manipulation in viscosity. Viscosity, as the term describes, is the measure of the resistance of a fluid to change in shape or flow. The viscosity of a fluid is the reciprocal of fluidity – the measure of ease of flow. The methodology employed a great perseverance of calculations and experiments in account of the unavailability of equipment to get ahead. This included repeatedly doing the same experiment to get a precise approximation to get the viscosity of the ink. The meticulous progression of the experiment to know how viscosity affects the flow of ink on the paper for a better glide while writing. The implications extend beyond just the experiment or the result, offering a better understanding of 3D printing applications, and providing more insights for further improvement of current ink jetting technology.[2]

Introduction –

Since its inception, ink—a solution that contains at least one colourant, such as dye or pigment—has undergone development. Its origins can be traced to the ancient world. The oldest inks were created using natural substances like gum, soot, and clay. Writing was done with these inks on papyrus, parchment, and other materials. Around 2500 BC, there is the oldest known instance of ink use in China.[3] The Chinese employed a variety of inks, such as sepia, carbon, and iron gall inks. In order to create carbon ink, soot or lampblack was combined with a gum binder. Iron sulphate, gallnuts, and gum were used to create iron gall ink. Sepia ink was made from the ink sac of the cuttlefish. Furthermore, from approximately 3000 BC, the Egyptians also employed ink. The Egyptians employed a variety of inks, such as vegetable, carbon, and gum Arabic ink.[3] In order to create carbon ink, soot or lampblack were combined with a gum binder. The sap of the acacia tree was used to make gum Arabic ink. Historically, plant juices from berries and leaves were used to make vegetable ink. The complexity of inks increased during the Middle Ages. Both new pigments and innovative ink-making techniques were created.In Europe, iron gall ink rose to become the most widely used kind of ink. It was a very strong, dark brown ink. The development of synthetic inks occurred in the 19th century.[4] These inks, which were derived from petroleum-based materials, dried far more quickly than the natural inks that had previously been utilised.[1] The inks currently in use are synthetic ones. Ink comes in a wide variety of forms today, each with special qualities of its own. Inks can be used for writing, printing, and drawing, among other things. Since ancient times, ink has been a useful and significant material.

Ink science is a complicated area that integrates physics, chemistry, and engineering. The kind of solvent, pigment, and additives used affect the ink's characteristics. The ink flows and dries according to the solvent. The ink's colour is determined by the pigment. The ink's qualities, such as its resistance to fading or its capacity to stick to a specific surface, can be improved by the additives. According to Sharon J. Huntington's account in an article for The Christian Science Monitor, the invention of a new ink manufactured from ferrous sulphate ($FeSO4$) and gallnut tannin brought about a revolution in the ink industry only approximately 1600 years ago. It was observed that when put on paper, it dyed bluish-black and fades into dull brown over time.

Despite being used and still being used as writing implements, quill, fountain, ball, felt, and gel pens also brought about improvements in ink chemistry. We will use a fountain pen as the experimental tool in this study in order to assess its effectiveness in causing a change in viscosity. The fountain pen offers the ideal advantage for this experimental study since it makes use of the capillary-drawn ink reservoir that is kept inside the pen. Capillary action is when water moves through a small opening due to the forces of adhesion and cohesion working against the gravitational force.) So, it is easier for the exchange of ink during experimentation and uses natural physics for writing. On the other hand, gel pen or ball pen uses much thicker ink and possesses a much more complex build than the former which might cause hindrance in the experimentation.

Furthermore, the efficiency not only depends on the viscosity of the ink but also on the type of paper. We'll use 80 GSM Copier paper, 70 GSM lined paper, and 60 GSM rough paper. These different kinds of paper are most generally used in schools and the education sector, where pens are used the most. Different types of paper possess different bindings and hence make a difference in the writing efficiency of ink. Some paper spreads ink, while on some, it glides. Viscosity does play a role in here, and I found an inquisitiveness to find how exactly. As a high school concept, the viscosity of a fluid is directly proportional to its temperature. So, manipulation in ink can be done by altering its temperature, filling it in a fountain pen, and running it on different papers to get the efficiency of ink. But this temperature change would be temporary and would cause problems during experimentation due to thermodynamic processes.

This can be overcome by using another prominent method of adding Glycerol to the sample ink. Glycerol has a viscosity of 1.5 Pa s which would make the ink viscous. By subjecting myself to this rigorous experimentation and observation, I aim to provide accurate and comprehensive data to the best of my capabilities. All the data and graphs represented are obtained through true experimentation.

Method of Experimentation -

- **To Find Viscosity of Sample Ink -**

  To measure the initial viscosity of the given ink sample, I filled three-fourths of the test tube with ink. Here, I used a 25 ml test tube. I found the mass of the test tube using the spring balance, and then calculated it again by filling three-fourths of the test tube with the ink. To find the mass of the ink (m), I subtracted the mass of the empty test tube from the mass of the test tube with ink.

  Mass of ink = Mass of test tube with ink - Mass of empty test tube

  Now, measure the volume of the ink (V) using the test tube. Then, measure the density of the liquid (p_l) -

  $$p_l = m/V$$

  I marked 1 inch above the base and below the surface of the ink of the test tube. I took an orbeez ball and calculated the mass (m) of it by measuring it using a balance. I measured around the center of the orbeez to get the circumference and divided it by 2π to get the radius. Using the radius, I found the volume (V) of the sphere. Now, using the mass and volume, I found the density (p_s) of the orbeez ball.

  $$p_s = m/V$$

  Later, I dipped it into the test tube. I clocked the timing until it touched the marked line of 1 inch above the base. I repeated it thrice to get the most accurate time (t). I measured the distance between the marked lines (D). Now calculate the velocity (V) of the sphere by dividing distance by time.

  $$V = D/t$$

  Now, calculate the viscosity of the liquid by using the formula[6] -

  $$\text{viscosity} = [2(p_s-p_l)gr^2]/9V$$

  where, p_s is the density of the sphere (in gm/ml)

p_l is the density of the liquid (in gm/ml)

V is the velocity of the sphere (in m/s)

g is the acceleration due to gravity (in m/s^2)

r is the radius of the sphere (in m)

- **Manipulating the viscosity of ink -**

❖ *Initial viscosity -*

Determined the viscosity of the initial ink sample by adding 18.75 ml of ink in a 25 ml test tube, extracted out the density of the ink, and calculated the density. The density displayed is 1.01 gm/ml. I took the orbeez and measured the radius and mass. With the radius, which is 0.00636 m, I found the volume and calculated the density which was 1.17 gm/ml. I marked the 1 inch from above and bottom as mentioned in the last section. Dropped the orbeez using tongs and clocked time. I did it thrice to get the most accurate timing of 1.56 seconds.

Later, I measured the distance between the marked points and calculated a velocity of 0.02 m/s. With this information, I found the viscosity to be 0.036 Pa s.

Initial viscosity = 0.036 Pa s

❖ Increase in viscosity -

To mark an increase in viscosity, I poured Glycerol in ink to increase its viscosity. To increase it significantly, I poured 40% of the solution in 60% of the ink to 18.75 ml.

To calculate the viscosity of glycerol ink, I performed the same experiment. This time, however, the orbeez floated and did not pass through the marked lines. So, I tried another mathematical formula to calculate the viscosity of the new ink.

The viscosity of new ink = (1 - % glycerol) * Viscosity of ink + % glycerol * Viscosity of glycerol

However, I performed the above-given experiment and calculated the viscosity of glycerol to be 1.4 Pa s.

Putting in the viscosity of the initial ink and glycerol, which is 1.4 Pa s, I found the value of the new ink to be 0.5816 Pa s.

Glycerol Ink = 0.5816 Pa s

❖ Decrease in viscosity

To mark a decrease in viscosity, I poured water into the ink to decrease its viscosity. To increase it significantly, I poured 40% of the solution in 60% of the ink to 18.75 ml.

I performed the above experimentation to find the viscosity of water and found it to be 0.001 Pa s

Therefore, I used the given formula to calculate the viscosity of new diluted ink.

The viscosity of new ink = (1 - % water) * Viscosity of ink + % water * Viscosity of water

Putting in the viscosity of the initial ink and water, which is 0.001 Pa s, I found the value of the new ink to be 0.022 Pa s.

Diluted ink = 0.022 Pa s

Results -

INITIAL INK -

60 GSM ROUGH PAPER - This is a low-quality yellow paper that usually spreads ink on the touch. When written on this paper, the pen felt to be entangled in its poor bonding, ran roughly missing in some characters, and created sharp tearing sounds. Though the ink did not spread enough on it, it was difficult to run this ink on the paper. The paper soaked less ink and showed light color. The efficiency of ink on this paper is poor and it gives a really poor experience.

70 GSM LINED PAPER - We usually use this paper in school notebooks and is most generally used everywhere. It has smooth pages but not enough for 80 GSM Copier Paper. When pen ran in this paper, it ran pretty smoothly, where characters and letters did not seem to miss and everything worked pretty well. The paper took more ink than 60 GSM but showed slight signs of being seen on the back page. The ink printed brightly and did not spread. Also, the pen ran smoothly on the paper and supported no leaks. The pen was quite efficient.

80 GSM COPIER PAPER - This blank white paper took ink gracefully and showed no sign of bleeding. The ink was not printed on the back page. The pen glided on the paper due to the ink, and the ink appeared darker and more efficient as it ran beautifully. It did not miss the characters and never felt hard to write.

Type of Paper	60 GSM	70 GSM	80 GSM
Bleed	No	No	No
Color Appearance	Dark Blue	Royal Blue	Dark Blue
Glided	Strong No	Yes	Strong Yes
Duration to dry off	Instantly	Instantly	Instantly
Printed on the back page	Yes	Partial Yes	No
Efficient	No	Yes	Strong Yes

Table 1. The efficiency of initial ink on different papers.

GLYCEROL INK -

60 GSM ROUGH PAPER - The viscous glycerol ink works quite lightly on this paper, where the ink on paper takes longer to dry off. Surprisingly, the pen did not bleed, but it was a little tough to write as the ink flew slowly through the nib. Also, the ink was quite printed on the back side of the paper. Therefore, the ink is not very efficient on this paper.

70 GSM LINED PAPER - The viscous glycerol ink ran quite smoothly on this paper, where it resembled the pilot pen in terms of smoothness, ink texture, and color. The ink took longer to dry off when compared to 60 GSM but surely ran faster and darker on this paper. The pen did not bleed as expected. Although the pen was quite tough when compared to the initial and diluted ink, it glided quite bravely. Here, the ink was found in traces on the back of the paper. Therefore, this ink is efficient on this paper

80 GSM COPIER PAPER - The viscous glycerol ink worked darker on this paper than 60 GSM and 70 GSM. The ink was quite liberal this time on paper and worked quite efficiently, but it took longer to dry off as with other cases. The ink did not bleed, but it traces quite noticeably on the back of the paper. This ink is efficient on this paper

Types of Paper	60 GSM	70 GSM	80 GSM
Bleed	NO	NO	NO
Color Appearance	Baby Blue	Dodger Blue	Denim

Glided	No	Yes	Strong Yes
Duration to Dry off	<1 second	1-2 second	2-3 second
Printed on the back page	Yes	Partial Yes	Partial Yes
Efficient	No	Yes	Strong Yes

Table 2. The efficiency of glycerol ink on different papers.

DILUTED INK -

60 GSM ROUGH PAPER - The less-viscous diluted ink works the lightest of all on this paper, where the ink on paper takes fractions to dry off. Surprisingly, the pen did not bleed, but it was a little tough to write as the ink flew swiftly through the nib. It worked roughly on this paper and traces on the back of the paper. This ink is not efficient on this paper.

70 GSM LINED PAPER - The less-viscous diluted ink ran quite smoothly on this paper in terms of smoothness, ink texture, and color. The ink instantly dries off on the paper. The pen did not bleed. The pen glided beautifully and left no traces on the back of the paper. While writing, the ink leaves some extra ink when lifted off the paper. This does not create much difference in writing style and dry efficiency. Also, the ink does not trace on the back of the paper. This ink is efficient on this paper.

80 GSM COPIER PAPER - The less-viscous diluted ink worked darker on this paper than 60 GSM and 70 GSM. The ink was the smoothest of all in any other cases in this experimentation and glided with pride. Surprisingly, the ink did not bleed; however, it took longer to dry off on this paper due to more water content. Also, the case of excess ink on lifting the paper was observed. Amazingly, it does not trace on the back of the paper. Therefore, this ink is highly efficient on this paper.

Type of Paper	60 GSM	70 GSM	80 GSM
Bleed	No	No	No
Color Appearance	Maya Blue	Baby Blue	Dodger Blue
Glided	Strong No	Yes	Strong Yes
Duration to dry off	Instantly	Instantly	1-2 Second

Printed on the back page	Yes	No	No
Efficient	No	Strong Yes	Strong Yes

Table 3. The efficiency of diluted ink on different papers.

Materials Required -

This research requires the following materials and equipment to perform the required experiments to find results -

- ☐ Test tube
- ☐ Spring Balance
- ☐ Fountain ink
- ☐ Types of paper
- ☐ Glycerol
- ☐ Water
- ☐ Orbeez ball
- ☐ Fountain pen
- ☐ Measurement cups
- ☐ Calculator
- ☐ Stopwatch.

Conclusion -

This study sought to examine the effectiveness of ink on various types of paper and discover how viscosity affects ink performance. The experiment involved manipulating the viscosity of the ink by adding glycerol and water. Through meticulous experimentation and observation, complete and accurate data were gathered. The experimentation proved that the efficiency of ink on paper changes as the viscosity is manipulated. The graphical representation on the observed change in efficiency is provided through the line graph.

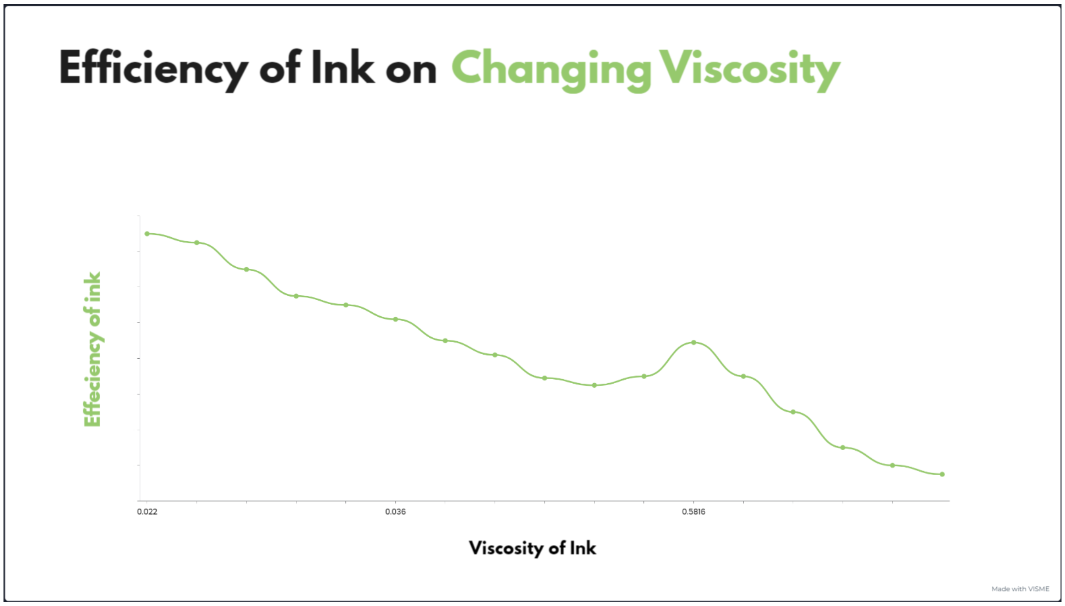

Figure 1. The efficiency of ink on the change of viscosity as observed through experimentation

The study's findings showed that the type of paper used and its viscosity are both factors in ink efficiency. Different varieties of paper had varying effects on the effectiveness of the ink; some spread the ink while others let it slide. The study attempted to mimic real-world circumstances by using 80 GSM Copier paper, 70 GSM lined paper, and 60 GSM rough paper that are frequently used in schools and the education sector.

Furthermore, the study explored the manipulation of ink viscosity by adding glycerol to the ink sample. Glycerol, with a viscosity of 1.4 Pa s, was used to increase the viscosity of the ink, and water, with a viscosity of 0.001 Pa s, was used to decrease the viscosity. This method provided a more controlled and stable approach compared to temperature manipulation, which could cause temporary changes and introduce difficulties during experimentation due to thermodynamic processes.

In conclusion, this study contributes valuable insights into the relationship between ink viscosity, paper type, and writing efficiency. The data and graphs presented in this study are the result of true experimentation, providing accurate and reliable information. The findings of this study can be applied in educational settings and other contexts where ink efficiency is of importance. Further research could explore additional factors influencing ink efficiency and investigate alternative methods to manipulate ink viscosity for improved writing experiences.

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