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# FLUIDERS

## SAYBOLT VISCOMETER

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# 1.Introduction:

***Viscosity is one of the most important physical properties of fluids***, as it represents the internal resistance to flow. engineers must measure viscosity Because it's needed in many applications, such as lubrication systems, pipeline design, chemical processing, and quality control. Our device is a classical device that is used for determination of **Newtonian fluids' kinematic viscosity and its name Saybolt Viscometer**

The working principle is simple measures the time it takes for a fixed volume (typically 60 ml) of fluid to flow through a standard orifice at a specified temperature

This project aims to simulate this process with a low-cost, Semi-automated alternative using modern sensors and microcontrollers.

***The main objective is to design and construct an Semi-automated***
***"Saybolt Viscometer"***

that provides live measurements and calculates viscosity with reasonable accuracy.

# 2.Design and Methodology:

## 2.1 Mechanical Design

- **Components**
    - Funnel
    - Beaker
    - Box
    - 2 Wooden bars

- **Box design**

The outer box was designed with Solidworks23. A Rectangular cut-out was included on the front panel for the LCD screen to allow clear visibility of the readings. Additionally, an opening was made at the top to securely insert the funnel used for fluid filling. The entire box was assembled using a tab-and-slot construction method, ensuring ease of assembly, precise alignment, and mechanical stability. Inside the box, the ultrasonic sensor was fixed in place using two horizontal support columns. These columns ensured that the sensor remained stable and accurately aligned above the beaker for consistent distance measurements.

## 2.2Sensor and Control System:

- **HC-SR04 ultrasonic sensor**

  The sensor sits right atop the beaker
  To measure the distance that is between the sensor and the rising
  liquid level.


- **ESP32 microcontroller**

  The **ESP32** microcontroller is used as the main control unit in the Saybolt Viscometer project. It is responsible for receiving data from sensors, processing the information, and displaying the results.

- **LCD**

  The screen is interfaced using multiple digital pins for direct control over each function (such as RS, EN, D4–D7), rather than using a simplified I2C communication

## 2.3 Operational Workflow

1. Fluid is poured into a funnel.
2. A beaker is placed under the funnel
3. Sensor measures the height of fluid
4. Height change is used to calculate time
5. Time for 60 ml to flow is calculated
6. Time is then used to calculate viscosity

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# 3. Calibration:

**Equation Format:**

The standard empirical equation is:

$$\boldsymbol{\nu = A \cdot t - \left(\frac{B}{t}\right)}$$

Where :

- $\nu$ : Kinematic viscosity (mm²/s or cSt)
- t : Flow time in seconds
- A,B : Constants to be determined by calibration

We made two calibrated equations, one for fast-flowing fluids and the other for slow-flowing fluids

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## 3.1: calibrating the equation for fast-flowing fluids

We used two equations for two different reference fluids to calculate the constants in Saybolt equation

### 1.Reference fluids:

1) **Water:**

   properties:
   - $\nu_{\text{water}} = 0.89\ \text{mm}^2/\text{s}$
   - Volume used = 60 ml
   - Measured discharge times (seconds):

     $$[3.32, 4.39, 3.32, 4.28, 3.21]$$
   - Average time :

     $$taverage_{for\ water} = (3.32 + 4.39 + 3.32 + 4.28 + 3.21) / 5 = 3.704\ s$$

2) **Milk:**

   properties:
   - $\nu_{\text{milk}} = 1.8\ \text{mm}^2/\text{s}$
   - Volume used = 60 ml
   - Measured discharge times (seconds):

     $$[7.6, 7.39, 6.64, 7.49, 7.82]$$
   - Average time :

     $$t_{averge\ for\ milk} = \frac{7.6+7.39+6.64+7.49+7.82}{5} = 7.388\ s$$

## 2.Substituting into the Equation :

$$1)\ For\ water\ :\ 0.89 = A * 3.704 - (\frac{B}{3.704})$$

$$2)\ For\ milk\ :\ 1.8 = A * 7.388 - (\frac{B}{7.388})$$

$$\underline{* \boldsymbol{Solving\ the\ two\ equations\ and\ we\ get\ A, B} *}$$

$$A = 0.2447656223$$

$$B = 0.06153034765$$

## 3.Final calibrated equation for fast-flowing fluids :

$$v = 0.2447656223 * t - (\frac{0.06153034765}{t})$$

---

## 3.2: calibrating the equation for slow-flowing fluids

We did the same process in oil.

1) **Substituting into the Equation :**

**Solving the two equations and we get A,B**

$$A = 1.297738228$$

$$B = -235.6160549$$

## 3.Final calibrated equation for slow-flowing fluids :

$$v = 1.297738228 * t - \left(\frac{-235.6160549}{t}\right)$$

# 4. Testing and Results:

## Results for Fast-Flowing Fluids

| Fluid | Time (s) | Viscosity ($mm^2/s$) |
|---|---|---|
| **Water** | 3.73 | 0.896 |
| **Water** | 4.28 | 1.033 |
| **Water** | 4.28 | 1.033 |
| **Water** | 3.75 | 0.901 |
| **Water** | 3.54 | 0.849 |
| **Milk** | 8.35 | 2.036 |
| **Milk** | 8.03 | 1.958 |
| **Milk** | 7.7 | 1.877 |
| **Milk** | 7.28 | 1.773 |
| **Milk** | 8.24 | 2.009 |

$$\textit{Accuracy for water readings} = 94.08\ \%$$

$$\textit{Accuracy for milk readings} = 92.74\ \%$$

## Results for Slow-Flowing Fluids

| Fluid | Time (s) | Viscosity ($mm^2/s$) |
|---|---|---|
| **Oil** | 13.95 | 34.993 |
| **Oil** | 14.13 | 35.012 |
| **Oil** | 18.94 | 37.019 |
| **Oil** | 16.8 | 35.827 |
| **Oil** | 17.34 | 36.091 |

$$\textit{Accuracy for Oil readings} = 97.75\ \%$$

# 5.Uncertainty Analysis:

An uncertainty analysis was conducted to evaluate the accuracy of the viscosity measurements and identify potential sources of error.

## 5.1 Sources of Uncertainty

Several sources of uncertainty were identified based on the experimental setup and device characteristics:

- **Sensor Resolution**: The HC-SR04 sensor has a resolution of 0.3 cm, limited by the speed of sound and timing accuracy. Small changes in fluid level below this resolution may lead to unstable measurements. Additionally, variations in air density or humidity affect the speed of sound, introducing further errors.
- **Wave Reflection**: The fluid surface (e.g., oil or water) may reflect ultrasonic waves unevenly due to turbulence or transparency, weakening the signal and reducing measurement reliability, especially for highly reflective fluids.
- **Power Supply**: The ESP32 supplies the HC-SR04 with 5V via USB or another source. Voltage fluctuations can affect sensor performance, leading to inaccurate measurements.
- **Viscometer Factors**: Impurities or non-uniformity in the fluid composition may affect flow time, causing variability in viscosity measurements. Mechanical vibrations or instability in the setup can also impact sensor stability.
- **Temperature Errors**: Fluid temperature deviations cause a 1–2% error in viscosity per degree Celsius, while environmental temperature affects the HC-SR04 by approximately 0.17% per degree Celsius. This can result in a cumulative error of 2,5% in flow time if conditions are not controlled.

## 5.2 Uncertainty Calculation

### Theoretical Basis

- The kinematic viscosity (v) is calculated using the standard Saybolt Viscometer Equation, which describes the relationship between the flow time of a fluid through a calibrated orifice and its viscous properties:

$$\boldsymbol{v = A * t - \frac{B}{t}}$$

- A and B are the calibration constants specific to the viscometer used. For the purpose of this analysis, the uncertainty in these constants is assumed to be negligible.

**1-Calculation of the Sensitivity Coefficient (dv/dt):** This coefficient indicates how much the viscosity changes with a change in flow time. It's calculated by taking the derivative of the viscosity equation with respect to time:

$$\frac{dv}{dt} = A + \frac{B}{T^2}$$

**2-Calculation of the Standard Uncertainty of the Mean Flow Time (ut ):** This uncertainty is estimated from the observed variability in repeated flow time measurements. If we have n flow time measurements, the standard uncertainty of the mean time is calculated from the standard deviation

$$Ut = \frac{std\_dev(t)}{\sqrt{n}}$$

**3-Assumption for Temperature Uncertainty (u_v _temperature)**=0

**4-Calculation of the Combined Standard Uncertainty (uc _(v)):** To combine the individual uncertainty contributions from all relevant sources into a single overall value, the Law of Propagation of Uncertainty is applied.

$$uc\_(v) = \sqrt{(\frac{dv}{dt} * Ut)^2 + u\_v\_temperature^2}$$

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## 5-Calculation of the Expanded Uncertainty (U):

To provide a wider confidence interval around the measured value (typically a 95% confidence level), the combined standard uncertainty is multiplied by a coverage factor (k). In this report, a coverage factor of k=2 was used to represent a 95% confidence level, which is a common assumption for normally distributed data.

$$U = K * uc\_(v)$$

We use MATLAB to calculate

MATLAB®

```
--- Analysing Water Measurements ---
Average Measured Viscosity for Water: 0.9427 cSt
Reference Viscosity for Water: 0.89 cSt
Standard Uncertainty for Water Time (u_t_water): 0.1531 seconds
Sensitivity Coefficient (dv/dt) for Water at average time 3.92 s: 0.2488 cSt/s
Uncertainty in Viscosity due to Temperature for Water (u_v_temperature_water): 0.0000 cSt (Assumed negligible)
Combined Standard Uncertainty for Water (uc_v_water): 0.0381 cSt
Expanded Uncertainty for Water (U_water) at 95% confidence (k=2): 0.0762 cSt
Water Viscosity: 0.9427 +/- 0.0762 cSt (at 95% confidence)
```

```
--- Analysing Milk Measurements ---
Average Measured Viscosity for Milk: 1.9308 cSt
Standard Uncertainty for Milk Time (u_t_milk): 0.1946 seconds
Sensitivity Coefficient (dv/dt) for Milk at average time 7.92 s: 0.2457 cSt/s
Uncertainty in Viscosity due to Temperature for Milk (u_v_temperature_milk): 0.0000 cSt (Assumed negligible)
Combined Standard Uncertainty for Milk (uc_v_milk): 0.0478 cSt
Expanded Uncertainty for Milk (U_milk) at 95% confidence (k=2): 0.0956 cSt
Milk Viscosity: 1.9308 +/- 0.0956 cSt (at 95% confidence)
```

```
--- Analysing Corn Oil Measurements ---
Average Measured Viscosity for Corn Oil: 35.7885 cSt
Reference Viscosity for Corn Oil: 35.00 cSt
Standard Uncertainty for Corn Oil Time (u_t_corn_oil): 0.9620 seconds
Sensitivity Coefficient (dv/dt) for Corn Oil at average time 16.23 s: 0.4035 cSt/s
Uncertainty in Viscosity due to Temperature for Corn Oil (u_v_temperature_corn_oil): 0.0000 cSt (Assumed negligible)
Combined Standard Uncertainty for Corn Oil (uc_v_corn_oil): 0.3882 cSt
Expanded Uncertainty for Corn Oil (U_corn_oil) at 95% confidence (k=2): 0.7763 cSt
Corn Oil Viscosity: 35.7885 +/- 0.7763 cSt (at 95% confidence)
```

```
--- Analysing Semsem Oil Measurements ---
Average Measured Viscosity for Semsem Oil: 38.2826 cSt
Standard Uncertainty for Semsem Oil Time (u_t_Semsem_oil): 0.6112 seconds
Sensitivity Coefficient (dv/dt) for Semsem Oil at average time 20.70 s: 0.7478 cSt/s
Uncertainty in Viscosity due to Temperature for Semsem Oil (u_v_temperature_sesame_oil): 0.0000 cSt (Assumed negligible)
Combined Standard Uncertainty for Sesame Oil (uc_v_Semsem_oil): 0.4571 cSt
Expanded Uncertainty for Semsem Oil (U_Semsem_oil) at 95% confidence (k=2): 0.9141 cSt
Semsem Oil Viscosity: 38.2826 +/- 0.9141 cSt (at 95% confidence)
```

# 6.Discussion

## 6.1 Strengths of the Design:

- Low Cost: Utilizes affordable components accessible to students and hobbyists.
- Automation: The process is fully automated, eliminating the need for manual timing and control.
- Live Feedback: Real-time readings are displayed on the LCD screen, enhancing usability.
- Hands-On Learning: The project provided valuable experience in coding, circuit design, and hardware troubleshooting.
- Redesign Success: After an initial failure, we successfully created a functional design that fits all components properly.

## 6.2 Limitations:

- Ultrasonic Sensor Sensitivity: Highly affected by environmental noise, leading to unstable readings unless properly isolated.
- Initial Design Flaws: The first prototype did not accommodate the board and components effectively.
- Connection Issues: Wiring and circuit stability required extra effort and learning through trial and error.
- Lack of Temperature Control: Saybolt standards require 40°C or 100°C testing, while our setup operates at room temperature.
- Mathematical Complexity: Calculations required for viscosity were initially difficult to apply correctly.

## 6.3 Future Improvements:

- Replace ultrasonic sensor with a more stable alternative or apply digital signal filtering.
- Incorporate temperature sensors (e.g., DS18B20) to comply with Saybolt standard conditions.
- Modular Hardware Design: Easier troubleshooting and component swapping.
- Enhance coding structure for scalability and easier debugging.
- Add data logging capability via SD card or Bluetooth module for record keeping.

### 6.4 Cost:

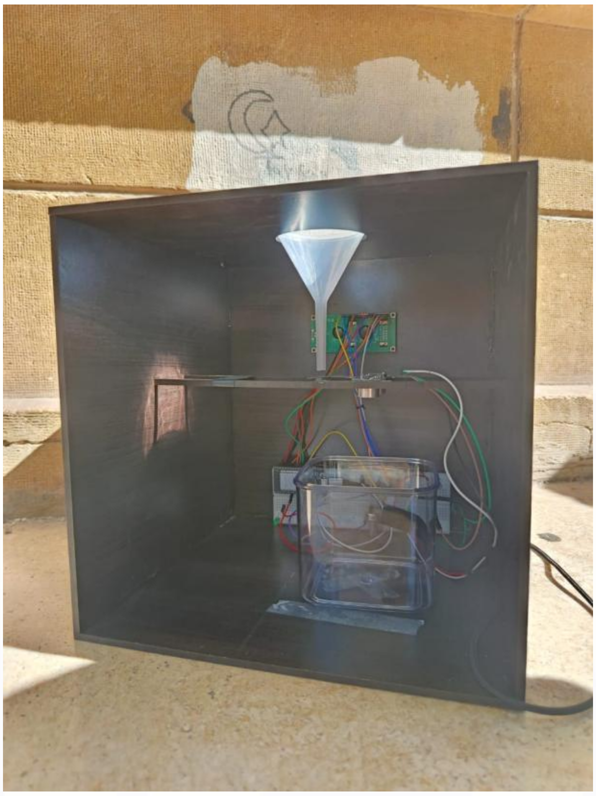
- ESP : 320EGP
- HC-SR04 ultrasonic sensor : 45EGP
- Character LCD 16*2 Display Module : 70 EGP
- Jumpers : 45 EGP
- Design : 280 EGP
- Resistors : 5 EGP
- Metal Potentiometer : 5.50 EGP
- Breadboard : 40 EGP
- Cone : 25 EGP
- Beaker : 40 EGP

**Total cost = 875.5** EGP

# 7.Conclusion

In conclusion, the Saybolt viscometer combined with an HC-SR04 ultrasonic sensor, ESP32 microcontroller introduces a novel low-cost digital method of measuring viscosity using digital accuracy for automatic data collection. Its accuracy is limited by uncertainties related to environmental influences on ultrasonic wave propagation, sensor resolution, microcontroller timing jitter, and fluid property or tube geometry variation. Using temperature compensation, careful calibration, stable power supplies, and sensor alignment, all these uncertainties can be reduced, making the system more reliable.

# 8. Project Gallery



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