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Fabrication of Falling Viscometer Using Inductive Proximity Sensor

Bandaru Nithin Kumar Varma[1], M Sumanth[2], Gade Hanimi Reddy[3], Mohammed Ajmal Shareef[4], Thota Naveen Kumar[5], C Ravi Chandramouli[6], Kallu Rajashekar[7]
[1, 2, 3, 4, 5]*Student, Sreyas Institute of Engineering and Technology, Hyderabad*
[6]*Managing Director, Quality Technologies Private Limited*
[7]*Assistant Professor, Sreyas Institute of Engineering and Technology, Hyderabad*

Abstract: Viscosity is the one of the major parameters to be considered in fluid related experiments and also in many industries. A new method of calculation of Dynamic Viscosity using the Viscometer which is easy for experimentation, with less calculation efforts, simple in design, construction with min. investment and no or minimum maintenance. This Paper intends to find the viscosity of Opaque fluids using falling ball viscometer. Falling Ball Viscometer works with Strokes law as the correction factor is multiplied in the calculation. As the correction factor is derived from the outcomes from the experiment and C-Code was written to make the calculation more efficient.

I. INTRODUCTION

Falling Ball Viscometer is a device which is used to measure the viscosity of the fluid with a very simple procedure. The procedure is that the tube is filled with the test fluid and the ball needs to drop from that particular tube. Time needs to be measured to reach the ball from point A to point B. by substituting the values in the formula we can get the viscosity.

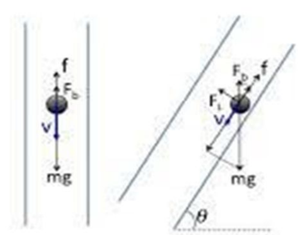


Figure 6.1 Free body diagram of ball in tube

When a solid sphere is dropped in a liquid, a viscous drag force will be exerted on the solid sphere. As per "Stoke's law, the drag force is proportional to the viscosity of the fluid" , the radius r of the solid sphere, and the velocity of the solid sphere

A. Derivation

From Strokes Law

$$f = 6\pi\mu rv$$

f = drag force

$$\mu = coefficient\ of\ viscosity$$

r = radius of ball

v = velocity of ball

$$\rho_{f= Density\ of\ Fluid}$$

$$\rho_{b= Density\ of\ Ball}$$

A high chromium high carbon steel ball is dropped into a fluid sample so that the gravitational force on the ball mg, is larger than the buoyant force . The net driving force F on the ball is:

$$F = m_g - f_b$$

f_b = buoyant force

$$F = m_g - f_b$$

$$= \rho \times v \times g - f_b$$

$$= \frac{4}{3} \times \pi \times r^3 \times \rho_b - \frac{4}{3} \times \pi \times r^3 \times \rho_f \times g$$

$$= \frac{4}{3} \times \pi \times r^3 \left(\rho_b - \rho_f\right) g$$

When the fluid of unknown viscosity is poured in the tube. The ball of known density is dropped in the tube containing the fluid. When the ball is dropped inside the tube, the ball experiences the buoyancy force acting upwards, acceleration due to gravitational force acting downwards and drag force. When the ball is dropped in the tube after some time the buoyancy force and acceleration due to gravitational force stabilizes and the ball will attain constant velocity.
When F=f, the solid sphere stops further acceleration and falls with a constant velocity.
If the ball acceleration is stopped because of buoyant force, the ball attains constant velocity.

Drag force= buoyant Force

$$f = 6\pi\mu r v$$

$$6\pi r v_f = \frac{4}{3} \times \pi \times r^3 \left(\rho_b - \rho_f\right) g$$

$$V_f = \frac{2r^2 \left(\rho_b - \rho_f\right) g}{9\mu}$$

$$\mu = \frac{2r^2 \left(\rho_b - \rho_f\right) g}{9V_f}$$

$$\mu = \frac{d^2 \left(\rho_b - \rho_f\right) gt}{18l}$$

$$\mu = \frac{54.4d^2 \left(\rho_b - \rho_f\right) t}{l}$$

The above equation can be modified as the ball drop occurs in a capillary tilted away from the vertical direction. Following the analysis of tangential force components along an inclined plane, the expression for viscosity is slightly modified, as follows

$$\mu = \frac{54.4d^2 \left(\rho_b - \rho_f\right) t.sin(angle)}{l}$$

II. FABRICATION OF EXPERIMENTAL SET-UP

For the fabrication of stand for the viscometer, we have reused scrab material available in the industry. We have used various machining operations such as Welding, Drilling, Cutting, grinding, Boring, surface finishing etc… Inorder to detect the balls in the opaque fluids Inductive Proximity Sensors (2 Nos.) are used.

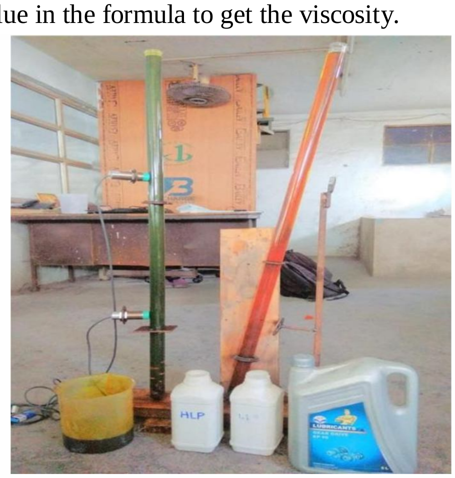
A. Inductive Proximity Sensor

Inductive Proximity sensor is the non-contact electronic proximity sensor which detects the position of metal elements. We have 2 inductive proximity sensors in which one is at point A and second is at point B which is 50cm apart. Sensing distance of the sensor is 20mm and the diameter of the sensor is 25mm. Operating voltage of the sensor is 9-24V, we have used 9V batteries(2 No.s) to activate the sensor which are connected in series inturn connected with operating switch


B. Experimentation

1) Tube in Vertical Position

a) Insert the tube in the space provided
b) Arrange the sensors perpendicular to the tube for better sensing range.
c) Pour the fluid in which the fluid viscosity to be measured.
d) Insert the ball in the tube so that the ball moves in the fluid
e) Using stopwatch measure time to travel from 1st sensor to 2nd sensor
f) Substitute the time value and density value in the formula to get the viscosity.



2) Tube Is Tilted To Certain Angle

a) Why does the Tube need to be Tilted?: When the ball is dropped in the tube the ball needs to move in a particular axis (approx. Straight line) but this will not happen in actual experiment (ref: - journal by Jay X Tang) the ball will deflect or change its axis in the tube. In order to avoid the axis deflection,we need to tilt the tube with a particular axis. In order to compensate for that tilting action. We Can derive correction factor up on experimentations

b) Experimentation

- Insert the tube in the space provided
- Arrange the sensors perpendicular to the tube for better sensing range.
- Pour the fluid in which the fluid viscosity to be measured.
- Insert the ball in the tube so that the ball moves in the fluid
- Using stopwatch measure time to travel by ball from 1st sensor to 2nd sensor
- Substitute the time value, angle and density value in the formula to get the viscosity.

C. Calibration Of Falling Sphere Viscometer

Calibration of Falling Ball viscometer is done using Zahn cup Viscometer for Heavy Liquid Paraffin and Gear Oil. B4 ford cup will measure the viscosity of the fluids between 25cs- 170cs

D. Apparatus Required

1) Zahn Cup(B4 ford cup) (IS33944)(100 ml)
2) Thermometer 0-100°c
3) Stop watch
4) 250 ml standard narrow necked flask
5) Given Sample of oil
6) Stand for holding Cup

$$V = 1.37t - \frac{200}{t}$$

where

V = kinematic viscosity, in centistokes; and

t = flow time, inseconds.

Zahn Cup Viscometer

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E. Calibration Tables

1) Vertical Case

S.no	Fluid	Zahn Cup viscometer (cp)	Vertical Falling Ball Viscometer (cp)
1	Heavy Liquid Paraffin	65.04	75.29
2	Gear Oil	137.85	148.04

Table Calibration of Zahn cup and Vertical Falling ball Viscometer

2) Tilted Case

S.no	Fluid	Zahn Cup viscometer (cp)	Tilted Falling Ball Viscometer (cp)
1	Heavy Liquid Paraffin	65.04	64.27
2	Gear Oil	137.85	139.47

Table 7.2 Calibration of Zahn cup and Tilted Falling ball Viscometer

III. OBSERVATIONS & FINDINGS

A. Zahn Cup Viscometer Observations

S.No	Fluid Name	Time (sec)	Viscosity (cp)
1	Heavy Liquid Paraffin	59	65.08
2	Gear oil	121	137.85

Table Zahn Cup Viscometer Readings

B. Falling Ball Viscometer Observations

1) Heavy Liquid Paraffin (Vertical Position)

S.No	Diameter of the Balls used (cm)	Distance travelled by the Ball (cm)	Time taken for ball to cover 50cm (sec)
1.	1.8	50	0.66
2.	1.8	50	0.61
3.	1.8	50	0.62
4.	1.8	50	0.65
5.	1.8	50	0.64
6	2.5	50	2.5
7	2.5	50	3.22
8	2.5	50	3.11
9	2.5	50	2.69
10	2.5	50	3.09

Table HLP Observation readings Of Falling Sphere Viscometer

2) Heavy Liquid Paraffin (Tilted 10^0 from Vertical)

S.No	Diameter of the Balls used (cm)	Distance travelled by the Ball (cm)	Time taken for ball to cover 50cm (sec)
1.	1.8	50	0.68
2.	1.8	50	0.65
3.	1.8	50	0.67
4.	1.8	50	0.64
5.	1.8	50	0.68
6	2.5	50	2.5
7	2.5	50	2.74
8	2.5	50	2.69
9	2.5	50	2.80
10	2.5	50	2.90

Table HLP (Tilted) Observation readings Of Falling Sphere Viscometer

3) Light Liquid Paraffin (Vertical Position)

S.No	Diameter of the Balls used (cm)	Distance travelled by the Ball (cm)	Time taken for ball to cover 50cm (sec)
1.	1.8	50	0.37
2.	1.8	50	0.3
3.	1.8	50	0.35
4.	1.8	50	0.31
5.	1.8	50	0.35

Table LLP Observation readings Of Falling Sphere Viscometer

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4) Light Liquid Paraffin (Tilted 10^0 from Vertical)

S.No	Diameter of the Balls used (cm)	Distance travelled by the Ball (cm)	Time taken for ball to cover 50cm (sec)
1.	1.8	50	0.37
2.	1.8	50	0.3
3.	1.8	50	0.35
4.	1.8	50	0.31
5.	1.8	50	0.35

Table LLP (Tilted) Observation readings Of Falling Sphere Viscometer

5) Gear Oil - 90 Oil (Vertical Position)

S.No	Diameter of the Balls used (cm)	Distance travelled by the Ball (cm)	Time taken for ball to cover 50cm (sec)
1.	1.8	50	1.32
2.	1.8	50	1.31
3.	1.8	50	1.39
4.	1.8	50	1.31
5.	1.8	50	1.33
6	2.5	50	10.41
7	2.5	50	9.88
8	2.5	50	10.04
9	2.5	50	9.87
10	2.5	50	9.94

Table Gear Oil (Vertical) Observation readings Of Falling Sphere Viscometer

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6) *Gear Oil - 90 Oil (Tilted 10^0 from Vertical)*

S.No	Diameter of the Balls used (cm)	Distance travelled by the Ball (cm)	Time taken for ball to cover 50cm (sec)
1.	1.8	50	1.17
2.	1.8	50	1.19
3.	1.8	50	1.2
4.	1.8	50	1.19
5.	1.8	50	1.21
6	2.5	50	5.73
7	2.5	50	5.84
8	2.5	50	5.90
9	2.5	50	5.88
10	2.5	50	5.95

Gear Oil (Tilted) Observation readings Of Falling Sphere Viscometer

7) *Rubber Process Oil (Vertical Position)*

S.No	Diameter of the Balls used (cm)	Distance travelled by the Ball (cm)	Time taken for ball to cover 50cm (sec)
1.	1.8	50	6.42
2.	1.8	50	6.54
3.	1.8	50	6.45
4.	1.8	50	6.1
5.	1.8	50	6.23
6	2.5	2.5	35
7	2.5	2.5	27.09
8	2.5	2.5	29.8
9	2.5	2.5	30
10	2.5	2.5	29.99

Table Process Oil (Vertical) Observation readings Of Falling Sphere Viscometer

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8) Rubber Process Oil (Tilted 10^0 from Vertical)

S.No	Diameter of the Balls used (cm)	Distance travelled by the Ball (cm)	Time taken for ball to cover 50cm (sec)
1.	1.8	50	6.08
2.	1.8	50	6.02
3.	1.8	50	6.06
4.	1.8	50	5.9
5.	1.8	50	6
6	1.8	50	31
7	1.8	50	31.5
8	1.8	50	30.06
9	1.8	50	31
10	1.8	50	31.01

Table Gear Oil (Tilted) Observation readings Of Falling Sphere Viscometer

C. Findings

On analyzing the calibrated values, we found a correction factor is required for some cases .Other findings have been mentioned below.

1) Major Findings: For Fluids of less than 15cp, the balls of D/d ratio less than 0.66 need to be used.
For the Fluid of Greater than 15 cp, the balls of D/d ratio 0.877 need to be used and have to multiply the correction factor of 0.5 to 0.65.
For Fluids of Greater than 15cp, in case a 1.8cm ball is used then the value needs to be multiple with the correction factor of 3.9 to 5.3.

IV. COST OPTIMIZATION

The Cost of the falling sphere viscometer was around two lakhs(Brookfield Viscometer) in the market but the viscometer manufactured by us is around 15 thousand only. The cost reduction was identified in the arrangement of the stand as it was prepared from industrial waste iron, wood pieces using various operations like welding, cutting, drilling etc in which all these are available in industry which is free of cost. The higher cost was observed in tubes and Sensors. The cost details are mentioned below.

A. Bill of Materials

S.no	Material	Quantity	Price
1	Tubes	3	12000
2	Sensors	2	1900
3	Ball Bearings	15	265
4	Battery	5	100
5	Batteries connecting cables	5	50
	Total		14315

Table Bill of Materials

C code for calculating viscosity

```
#include <stdio.h>
void main()
{
   double den1,den2,ang,t,d,v;
   printf("enter the angle of the set up: ");
   scanf("%lf",&ang);
    printf("enter the diameter of the ball: ");
   scanf("%lf",&d);
   printf("enter the density of ball: ");
   scanf("%lf",&den1);
   printf("enter the density of fluid: ");
   scanf("%lf",&den2);
   printf("enter the time period taken for the ball: ");
   scanf("%lf",&t);
   if(ang==90)
   {
               if(den2<=0.8)
          {
              v=1.09*(d*d)*(den1-den2)*t;
              printf("the viscosity of the fluid is : %f",v);
           }
               else
             {
                     if(d==2.5)
                    {
                         v=1.09*(d*d)*(den1-den2)*t*0.575;
                           printf("the viscosity of the fluid is:-%f",v);
             }
                             if(d==1.8)
            {
```

```
                v=1.09*(d*d)*(den1-den2)*t*4.6;
                printf("the viscosity of the fluid is :: %f",v);
            }
        }
    }
    else
    {
        if(ang==80)
        {
            if(den2<=0.8)
            {
                v=1.09*(d*d)*(den1-den2)*t*0.98;
                printf("the viscosity of the fluid is= %f",v);
            }
            else
            {
                if(d==2.5)
                {
                    v=1.09*(d*d)*(den1-den2)*t*0.98*0.577;
                    printf("the viscosity of the fluid is.= %f",v);
                }
                if(d==1.8)
                {
                    v=1.09*(d*d)*(den1-den2)*t*0.98*4.6;
                    printf("the viscosity of the fluid is/ %f",v);
                }
            }
        }
    }
}
```

V. RESULTS

1) Comparison of Zahn Cup and Vertical Falling Sphere Viscometer

S.no	Fluid	Viscosity of fluid measured using Zahn Cup viscometer (cp)	Viscosity after multiplying with correction factor (cp)	Error
1	Heavy Liquid Paraffin	65.04	75.02	around 15%
2	Gear Oil	137.85	148.5	around 8%

Table Comparison of Viscosities of Zahn cup and Vertical Falling ball viscometer

2) Comparison of Zahn Cup and Tilted Falling Sphere Viscometer

S.no	Fluid	Viscosity measured using Zahn Cup viscometer (cp)	Viscosity after multiplying with correction factorTilted Falling Ball Viscometer (cp)	Error
1	Heavy Liquid Paraffin	65.04	64.5	Around 5%
2	Gear Oil	137.85	139.92	Around 5%

Table Comparison of Viscosities of Zahn cup and Tilted Falling ball Viscometer

3) Comparison of Actual Viscosity and Tilted Falling Sphere Viscometer

S. no	Fluid	Actual Viscosity (cp)	Viscosity after multiplying with correction factorTilted Falling Ball Viscometer (cp)	Error
1	Light liquid Paraffin	11	9.88	Around 10%
2	Rubber Process oil	950	900	Around 5%

Table Comparison of Viscosities of Actual Viscosity and Tilted Falling ball Viscometer

4) Comparison of Actual Viscosity and Vertical Falling Sphere Viscometer

S.no	Fluid	Actual Viscosity	Viscosity after multiplying with correction factorTilted Falling Ball Viscometer (cp)	Error
1	Light liquid Paraffin	11	9.10	Around 10%
2	Rubber Process oil	950	850	Around 5%

Table Comparison of Viscosities of Actual Viscosity and Tilted Falling ball Viscometer

VI. CONCLUSION

Fabrication of Falling Sphere Viscometer is done by recycling the resources available in the Industry and optimized the cost greatly. Falling Viscometer not only measures Transparent Fluids but also opaque fluids like Paints, oils etc… By analyzing the Calibrated values we found that there is a need of a Correction factor and detailed findings have mentioned above. By analyzing the results we found Tilted Falling Ball viscometer is very Efficient than Vertical Falling Ball viscometer with error of around 5%.

VII. ACKNOWLEDGEMENT

We thank to the Managing Director of "Quality Technologies Private Limited" Mr. Ravi Chandra Mouli for granting us access to conduct such type of experiment at their work place to get a great experience.

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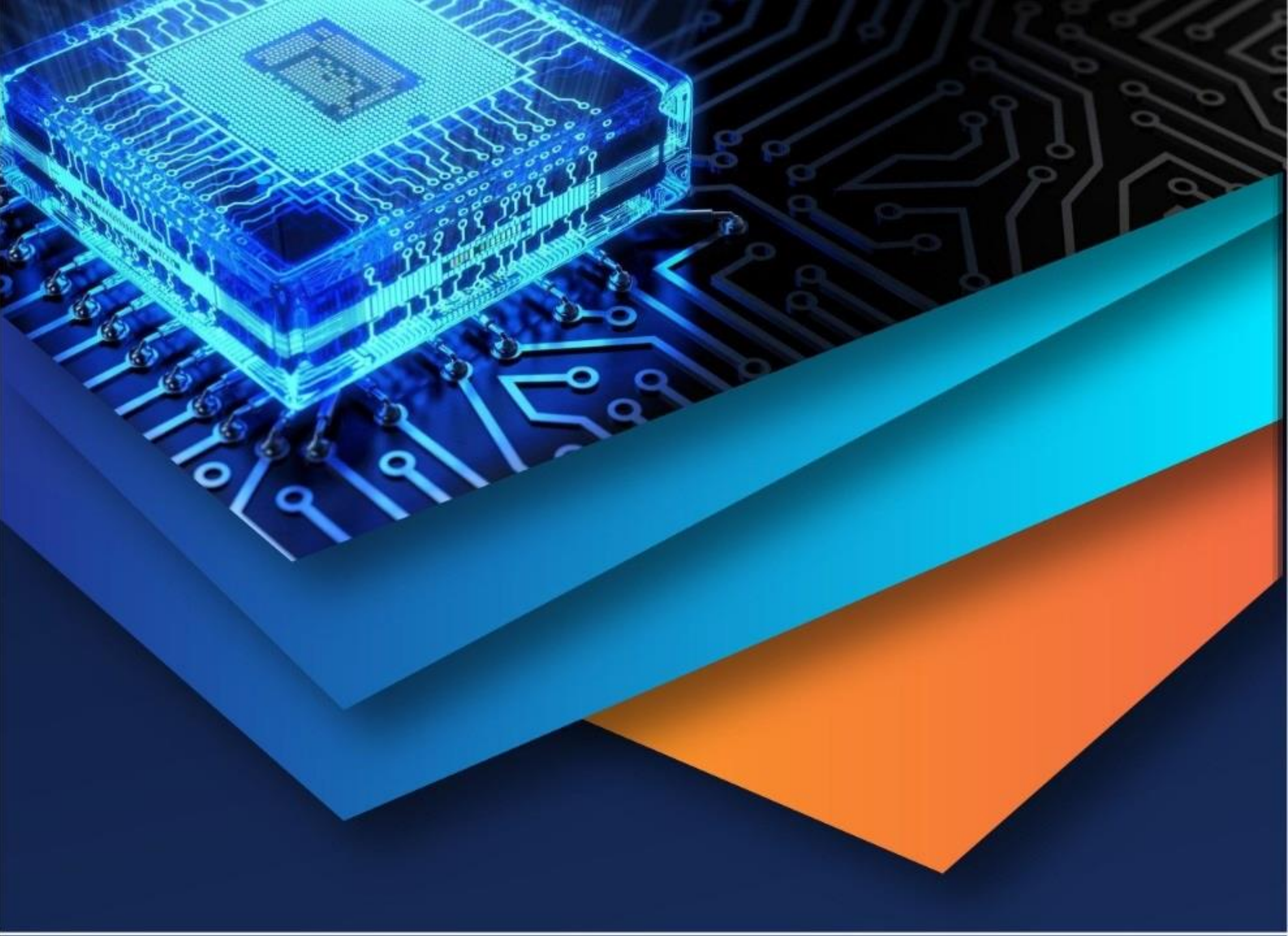

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