MEASUREMENT OF DIMENSIONAL PARAMETERS IN UBBELOHDE TYPE VISCOMETERS USING DIGITAL IMAGES

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Abstract: A National Metrology Institute (NMI) must obtain the best possible results in the measurements of its quantities. Due to this, the results for all influence quantities must be validated with the purpose of acquiring a better measurement uncertainty estimate. This article shows a methodology used to obtain dimensional measurements from capillary viscometers, using digital images of viscometers and dimensional standards as reference. These measurements cannot be obtained through direct methods of dimensional measurement (eg.: caliper, micrometer, etc).

Key words: viscosity, dimensional, digital image, measurement uncertainty.

1. INTRODUCTION

Fluids Laboratory (Laflu) of the Division of Mechanical metrology (Dimec) of the Brazilian National Metrology Institute (INMETRO) is responsible for providing traceability to measurements of kinematic viscosity in Brazil. Its competence is proven through international intercomparisons [1] and its services are registered in appendix C of BIPM [2].

Viscosity is a fundamental characteristic property of all liquids. When a liquid flows, it has an internal resistante to flow. Viscosity is a measure of this resistance to flow or shear. Dynamic viscosity is the tangential force per unit area required to slide a layer against another, when the two layers are kept at a unit distance. With the knowledge of the liquid's density at a certain temperature, it is possible to define kinematic viscosity as the rate between the liquid's dynamic viscosity and its density [3].

The viscometer is an instrument with many types and models to measure viscosity. In this article it will be used a DIN Ubbelohde type viscometer [4] which is the model used to measure Newtonians fluid's viscosity in Laflu.

To determine the kinematic viscosity using this viscometer, various parameters are used in order to correct the measured value, as seen in equations 1 through 4. Among these are the dimensional measurements of the viscometer which act in the time correction, in equation 3, and also in the surface tension correction, in equation 4.

$$\nu = K_1 \times \left(t - C_t\right) \tag{1}$$

$$K_1 = K_2 C_T C_A C_G C_{ST} \tag{2}$$

$$C_t = \left[\frac{0,00166\sqrt{V^3}}{L \cdot K_2 \cdot \sqrt{K_2 d}} \times \frac{1}{t^2}\right] \tag{3}$$

$$C_{ST} = \left[1 + \frac{2}{g_1 h} \times \left(\frac{1}{r_u} - \frac{1}{r_l}\right) \times \left(\frac{\sigma_1}{\rho_1} - \frac{\sigma_2}{\rho_2}\right)\right] \tag{4}$$

ν is the fluid's kinematic viscosity calculated at the reference temperature;

K_1 is the viscometer's constant with corrections for the measurements conditions;

t is the flow time;

C_t is the correction for time (kinetic energy correction);

K_2 is the calibrated viscometer's constant;

C_T is the correction for temperature during measurement;

C_A is the correction for angle variation between the calibration moment and the measurement moment;

C_G is the correction for gravity between the calibration moment and the measurement moment;

C_{ST} is the correction for surface tension between the calibration moment and the measurement moment;

V is the volume of the flown liquid;

L is the capillary lenght;

d is the capillary diameter;

g_1 is the gravitational acceleration in the measurement location;

h is the average length of the driving head

r_u is the average radius of the upper meniscus;

r_l is the average radius of the lower meniscus;

σ_1 is the measured surface tension of the oil;

σ_2 is measured the surface tension of the calibration oil;

ρ_1 is the measured density of the oil;

ρ_2 is the measured density of the calibration oil.

During 2009's peer review one of the findings was: "Uncertainty contribution due to kinetic energy and surface tension effects are evaluated according to ISO and DIN standards. There is a need to validate the uncertainty contributions by experimental methods" [5]. By solving this finding it is possible to gage the effect that these values have on each viscometer due to their differences in construction in comparison to the standard's values.

With these results, Laflu can obtain an independent scale for viscosity. The dimensional parameters of the standard viscometers to be determined are shown in figure 1:

- Volume of the flown liquid (*V*);
- Capillary diameter (*d*);
- Driving head (*h*);
- Capillary length (*L*);
- Internal radius of the upper tube (r_u);
- Internal radius of the lower tube (r_l).

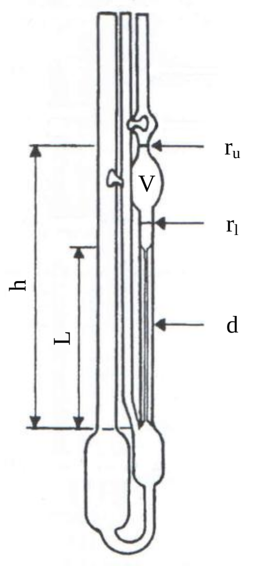

Figure 1 – Ubbelohde viscometer parameters

Due to the difficulty in directly obtaining these measurements (e.g. using a caliper or a micrometer), a digital imaging processing method is proposed in this paper, showing results for the capillary diameter.

2. MATERIALS AND METHODS

To obtain a digital image it was used a Digital Single-Lens Reflex (DSLR) camera, Canon EOS 450D, with an 18-200m Sigma lens, with a macro of 0,45 m. The camera was connected with the computer using its USB port and operated using the *EOS Utility* software, which is able to control the focus of the lens with no physical interaction between user and camera, allowing for better stability of the camera.

The viscometer was located in a leveled surface and at a known distance from the camera in order to have a constant magnification. In order to provide a contrast between the glass and the dimensional standard, it was used water with a red pigment as shown in figure 2.

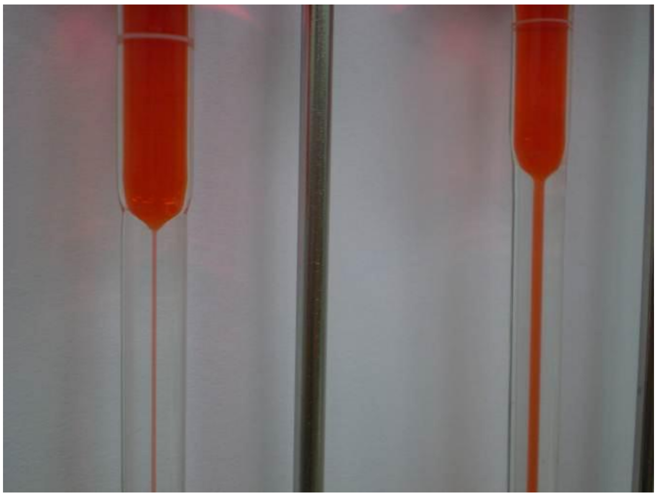

Figure 2 – Viscosimeter's capillary with colored water

However, with only the viscometer in the picture, it is possible to determine the diameter of the capillary in pixels. In order to have means of comparison between measures in pixels and millimeters, a dimensional standard needs to be positioned in the same plane as the capillary, so both the capillary and the dimensional standard are in focus [6]. Figure 3 shows a viscometer placed beside the dimensional standard used (a caliper's scale).

Figure 3 – Capillary viscometer and digital caliper's scale

In order to convert a pixel measurement to millimeters, first, the rate of millimeters that each pixel measures needs to be calculated from the standard, as in equation 5.

$$rate_{[\mathrm{mm}/px]} = \frac{s_{[\mathrm{mm}]}}{s_{[\mathrm{px}]}} \tag{5}$$

Where:

$s_{[\mathrm{mm}]}$ is the standard's measurement, in mm;

$s_{[\mathrm{px}]}$ is the standard's measurement, in pixels.

It is important to stress that this rate is valid for this image only, not being means of "calibrating" a pixel's measurement for neither this picture nor this camera.

After calculating this rate, the measurement can be made by multiplying this rate with the actual pixel measurement of the object, as in equation 6.

$$d_{[\mathrm{mm}]} = d_{[\mathrm{px}]} \times rate_{[\mathrm{mm}/px]} \tag{6}$$

Where:

$d_{[mm]}$ is the desired measurement, in mm;

$d_{[px]}$ is the desired measurement, in pixels.

3. IMAGE PROCESSING

To apply the method described in section 2, the measurements were extracted from the image using the software Matlab. After loading the image, the two sections of interest (the capillary and the caliper's scale) are separated. With this, two thresholds need to be used, one between the background and the capillary and the other between the scale's background and the scale's markings. Both thresholds are fixed and found empirically.

After determining the thresholds, both images need to be binarized. The thresholding is done using the rules from equations 7 and 8, respectively, for the capillary and the scale.

$$p(i,j) = \begin{cases} 0 \text{ if } p(i,j) > T_c \\ 1 \text{ if } p(i,j) \leq T_c \end{cases} \tag{7}$$

$$p(i,j) = \begin{cases} 0 \text{ if } p(i,j) > T_s \\ 1 \text{ if } p(i,j) \leq T_s \end{cases} \tag{8}$$

Where:

i is the line coordinate of the pixel;

j is the column coordinate of the pixel;

$p(i,j)$ is the pixel value at coordinates (i,j);

T_C is the threshold used for the capillary;

T_S is the threshold used for the scale.

Figure 4 shows Matlab's figure window with both the capillary and the scale after their respective threshold transformations.

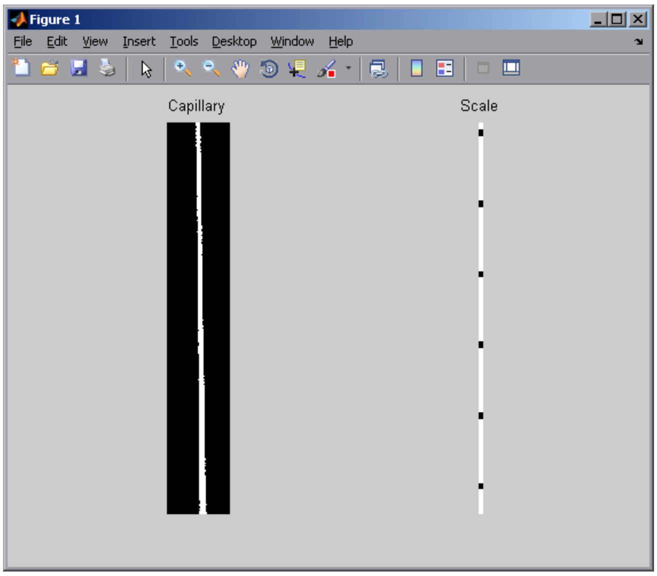

Figure 4 – Matlab's image window showing both areas of interest

After binarizing the scale, it is used an algorithm, shown in figure 5, to measure the length, in pixel, between every two of the caliper's markings, which measures 10 mm. This is done in the whole markings area, which was shown in the right side of figure 4. After this measure, and also knowing the total length of the captured caliper's scale, equation 5 is used to find the rate.

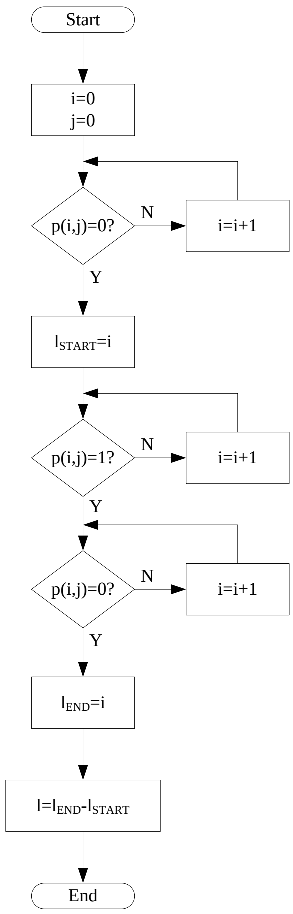

Figure 5 – Scale counting algorithm

In the capillary's image, the diameter is calculated for each line of the binary matrix and then calculated its mean value and standard deviation, which are then multiplied by the previously found rate, as in equation 6, in order to have a millimeter value.

4. RESULTS

According to standard ISO 3105 [4] there are 15 sizes of DIN Ubbelohde viscometers and, for this paper, a size 0 viscometer was chosen due to its thinnest capillary since it could prove to be a more challenging measure than other sizes.

A viscometer of this type must have the capillary's internal diameter's measure of about 0,36 mm [4]. Using the image processing techniques developed in this paper, a value of 0,35 mm has been found for this diameter.

5. CONCLUSION

With the dimensional values determined using this methodology, it is possible to compare the measured values with the theoretical values defined by the standard ISO 3105 [4]. A difference of 3 % was found when comparing the value obtained through this work and the standard value.

The knowledge obtained in this work, has enabled Laflu to further research into the measure of the other viscometers dimensional parameters, as stated in section 2.

This study can also be adapted to use with other viscometer sizes and types, such as those contemplated in ISO 3105 [4] and also ASTM D446 [7].

Various difficulties were found through this research, such as: thresholding, homogenous lighting, leveling of surface, contrast between fluid inside capillary and background. All of these are the subject of future studies in order to improve the measuring capabilities of the laboratory.

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