Automated Measurement of Viscosity with Ubbelohde Viscometers, Camera Unit and Image Processing Software

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ABSTRACT

Ubbelohde viscometers are common devices for the measurement of liquid viscosity. In an Ubbelohde viscometer the time that the liquid level takes to flow between two ring marks indicates the viscosity of the test fluid. In non-automated viscometers this time is measured using stopwatches. To improve the repeatability of the measurements and to increase the accuracy, an additional camera system is included. The image is analyzed in Matlab and the current liquid level (meniscus) is detected automatically. The system is therefore able to measure automatically the time needed between the two ring marks at the viscometer. To improve the accuracy of the system various methods for analyzing the data have been implemented. The results show a significant increase of repeatability.

1. INTRODUCTION

The Ubbelohde viscometers are used for the measurement of kinematic viscosity of Newtonian liquids that are sufficiently transparent to enable the meniscus of the liquid to be observed during measurement. Fig. 1 shows a schematic picture of Ubbelode viscometer con suspended level.

The viscosity of the test liquid is determined by measuring the time it takes for the sample, whose volume is defined by two ring-shaped marks to flow laminarly through a capillary under the influence of gravity [2, 3]. Hence, the friction within the liquid with high viscosity needs more time to pass the distance between the two measuring marks within the capillary tube. In accurate measurements these time is mostly measured by stopwatches.

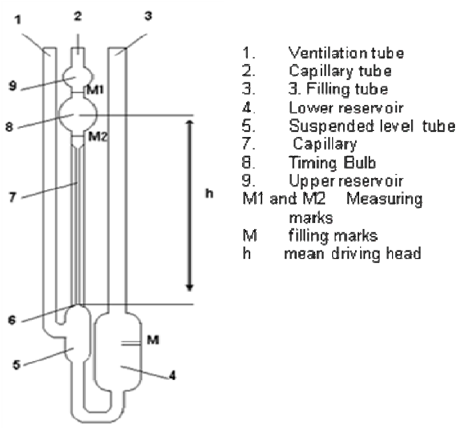

Fig. 1. Ubbelohde viscometer.

Another method for measuring the flow time is implemented in automatic viscometers, in which additional sensors detect the time it takes for the sample to flow. Up to date these automatic viscometers are mainly used in measurements with not very high accuracy requirements. Sometimes, the uncertainty of these devices can be higher than the uncertainty achieved in manual measurements with stopwatches. Nevertheless to measure the time with stopwatches also has its disadvantages and uncertainties which have to be considered.

Due to the existence of natural human hand and eye deviations during the measurement, there is always uncertainty left. Furthermore, it is sometimes necessary to wait up to 20 min until the liquid passes the second measuring mark. If this moment is missed another measurement is necessary.

For that reason a system has been developed which is designed for highest accuracy requirements, which works automatically. Those high requirements are necessary for example for the comparison of reference standards.

Fig. 2 shows the chosen set-up to achieve these goals. A camera system is watching the viscometers. The image data is processed with software written in Matlab. This software detects the meniscus of the liquid and identifies the crossing of the measuring marks.

The camera is a usual webcam with a resolution of 640x480 pixels. Advantages of such a camera are good availability and easy possibilities to read the data directly with Matlab.

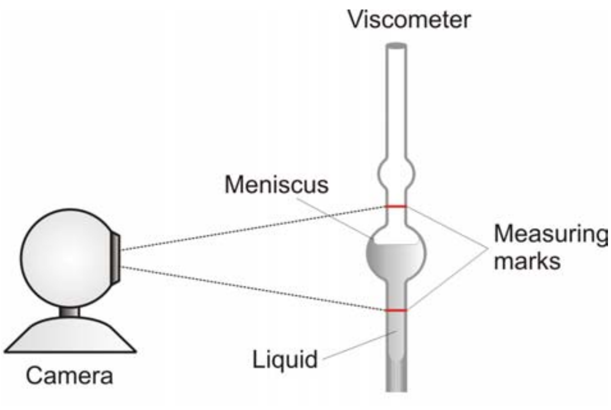

Fig. 2. Measuring device.

2. IMAGE PREPARATION

In the first step the image data of the camera is converted in a black and white image. Fig. 3 shows the image obtained by Matlab.

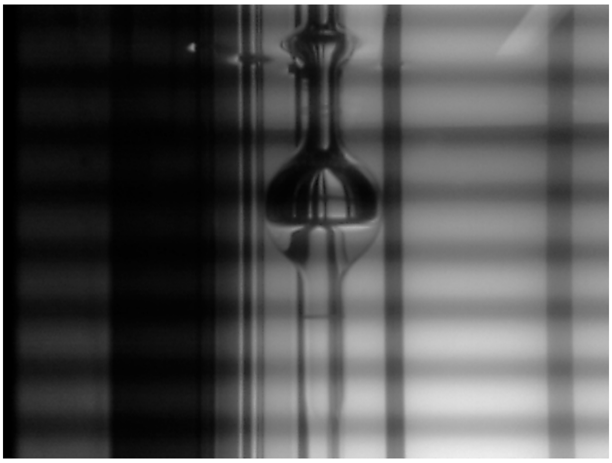

Fig. 3. Camera Image in Matlab.

Probably due to the sample rate of the camera, as well as an inconstant light in the background, stripes are visible, that slowly move downwards within the picture. Since these stripes are aligned in the same direction as the meniscus of the liquid this behavior disturbs each form of meniscus detection. For that reason the camera is turned by 90 degrees. In Matlab the image data is rotated back to the original alignment. Fig. 4 shows the picture obtained by this method. The resulting vertical stripes have no further influence on the results. The next step is a manual image preparation. First the edges at the left, top and right side of the viscometer have to be cut. The user marks the edges with the mouse pointer and Matlab stores this information and cuts the all following pictures as desired. Next, the position of the measuring marks has to be indicated by the user with the mouse pointer again. An automatic detection fails so far due to weak visibility within the picture. After that, the picture is prepared for meniscus detection.

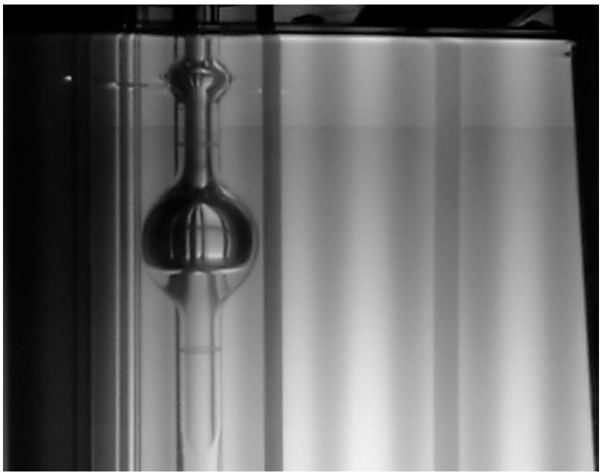

Fig. 4. Image by a 90° rotated camera.

3. MENISCUS DETECTION OF THE LIQUID

Since the meniscus is visible as a horizontal line in the picture a very simple and fast form of line detection can be applied.

All these brightness numbers are added in a horizontal line. A high result therefore represents a bright horizontal line.

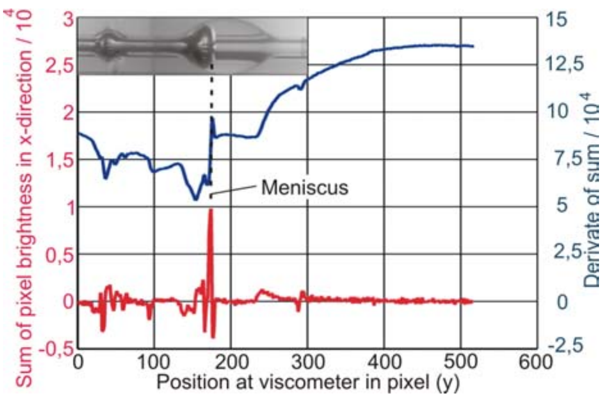

Fig. 5. Detection of liquid level.

Each pixel in the picture has a value between 0 and 255, whereby 0 stands for perfectly black and 255 for perfectly white. All values in between are a gray color. Lower numbers are a dark gray and higher ones a bright gray.

Fig. 5 shows the principle in a graph. The viscometer is visible at the upper left corner turned by 90°. At the left (above) of the meniscus a lot of dark points are visible. At the right (below) there is a very bright area visible.

The graph shows a high increase of light at this level. This increase is especially visible as a peak in the derivate of the sum. The derivate is therefore particularly suitable for the detection of the meniscus.

After starting the program it searches for the highest peak within the first 50 points to detect the meniscus. The found meniscus is shown to the user as a white line within the image.

To follow the meniscus of the liquid between each image of the camera, sum and derivate of the following image is produced again and the program checks whether the peak moved within the next three pixels. If that is the case, the stored meniscus level is set to that new peak.

The searching range of three pixels is important since flickers and noise in the image could otherwise lead to a jump of the detected meniscus in another part of the image. The searching range can also be adapted to the current measurement, but a value of three seemed to be useful for the majority of experiments.

Now, the program is running in a circle: Each time its reading the image from the camera, it cuts the edges as specified before by the user, turns it by 90°, produces sum and derivate and looks weather there is a higher peak within the next three pixel or not.

The new highest peak (meniscus level) is stored together with the time stamp of the camera. At the end of the measurement a graph of the meniscus level can be plotted as shown in Fig. 6.

The two horizontal lines in the figure represent the position of the ring marks at the viscometer. The liquid is accelerating first, crossing the upper ring mark and then moving to the wider part of the viscometer, where it is decelerating. In the lower part of the viscometer it is accelerating again and crossing the lower ring mark. The liquid flow around the ring marks shows a linear behavior.

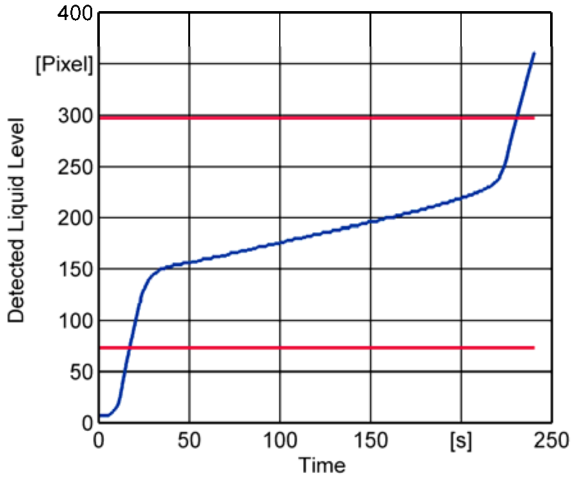

Fig. 6. Liquid level during a measurement.

4. TIME MEASUREMENT

The goal of the program is to measure the time which the liquid needs to pass the two ring marks precisely. Various effects lower the precision of the measurement: First, the camera takes pictures in intervals of about 100 ms, but a precision of less than 5 ms is desired. Second, the liquid detection sometimes produces little jumps especially close to the ring marks. The reason for that is that the ring mark is visible as a line similar to the meniscus. At a point close to it the line detection algorithm can be mislead easily (Fig. 7*)* and jumps to the point until the liquid passes the ring mark.

To overcome these problems it is made use of the fact that the liquid flow around the ring marks shows a very linear behavior.

A regression line is applied which uses the measured points before and after the ring mark. Fig. 7 shows the regression line with all measured points close to the lower ring mark. To find the regression line a standard algorithm is used. The sum of the perpendicular quadratic distance from all points to this line is minimal. For a further improvement of accuracy the next step is the search of the outliers of the data. This is done by looking for points which have the highest distance from the regression line. These points are deleted and a new regression line is calculated. In the next step, the moment in which the liquid crossed the ring mark is calculated. This is done by calculating the intersection of the regression line and the ring mark line.

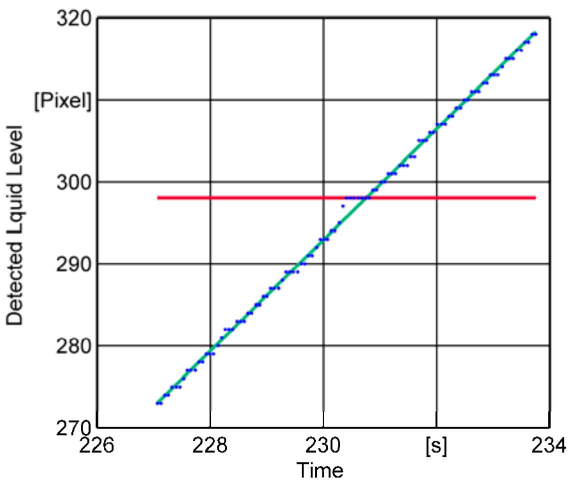

Fig. 7. Liquid level at lower ring mark

The regression line is given by equation (1):

$$y = mx + b \quad (1)$$

Whereas m is the slope, t the time and b the intersection with the y-axis at point t=0.

The time at the intersection can therefore be calculated by Eq. (2):

$$t_{rm} = (rm - b)/m\,, \quad (2)$$

where “rm” stands for ring mark position. These calculations are realized for the upper and the lower ring mark. The time passed between the two ring marks can then be calculated by subtracting both from each other.

5. RESULTS

A standard viscosity measurement consists of five measurements [2]. These have been realized manually with a stopwatch and with the camera set-up.

Table 1. Measurements carried out with automatic camera device and manual stopwatch.

Number	Camera [s]	Chron. [s]	Diff. [s]
1	213.403	213.49	-0.087
2	213.272	213.14	+0.132
3	213.521	213.28	+0.241
4	213.282	213.06	+0.222
5	213.422	213.31	+0.112

The measured liquid is Poly alpha Olefin at a temperature of 45,°C.

The time of the camera measurements varies less and shows therefore a better repeatability. The quality of the measurements can be calculated according to [2] with the following Eq. (3):

$$\varepsilon_t = \frac{t_{\max} - t_{\min}}{t}\,, \quad (3)$$

whereas, t_{max} *and* t_{min} is the longest and shortest flow time respectively, of a measuring series of 5 flow times, t is the flow time and ε_t is the relative difference of flow times in a series of measurements using one viscometer. According to [2], the value should be $\boldsymbol{\varepsilon_t \leq 2 \cdot 10^{-3}}$

The relative differences for the measurements with camera and with stopwatches are $\boldsymbol{\varepsilon_t = 1{,}17\ 10^{-3}}$ and $\boldsymbol{\varepsilon_t = 2{,}02\ 10^{-3}}$, respectively. The results are not verified for a greater number of experiments and can therefore not be regarded as a statistical proof, but these first experiments show the general tendency and promising results.

6. DISCUSSION AND OUTLOOK

Up to date the presented set-up is measuring at the top and lower marking ring in an angle. An automatic detection of the ring positions is not yet implemented and the middle position needs to be marked by the user. A slightly different position leads to a systematical error of the time measurement. In the shown experiment a position error of the upper marking rings of one pixel leads to an error of 12 ms. A pixel difference at the lower marking ring leads to a difference of 15 ms. The difference between lower and upper marking ring is due to the different liquid flow speeds in the upper and lower part due to the different hydrostatic pressure.

A possible improvement option is a second camera. In that case each camera could observe the marking ring at its height. In that case the marking ring is visible as a single line and can be detected more easily and with an improved accuracy. An improved resolution of the camera would additionally lead to superior results.

Alternative solutions are cameras with zoom to observe especially the area of the marking rings. The presented set-up considers the flow speed of the liquid as constant and uses a linear method for the regression line. In reality the flow speed shows a digressive behavior.

However this behavior is hardly visible in the diagram of Fig. 7. For that reason it is supposed that this influence is within a negligible range and does not need further consideration.

The proposed line detection and line following method is suitable for the presented set-up, but in another environment a different illumination can lead to problems. The line detection can stop at a line which shows higher differential amplitude of the sum (according to Fig. 5) than the actual meniscus of the liquid. The algorithm stops at this point without following the meniscus anymore. For that reason the detection algorithm has to be improved for higher reliability in the future application. A possible solution might be the observation of several peaks in the line detection and an automatic detection of “moving” peaks.

Nevertheless the viscosity detection with a camera shows promising results and high repeatability rates and is a future option to replace stopwatches in viscosity measurements of high accuracy.

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