Mobile Phone Enabled Pervasive Measurement of Liquid Viscosity

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Abstract:
A new conceptual non-contact method for liquid viscosity measurement in capillary tube using mobile phone as the data acquisition facility is proposed. The video and image for the capillary force driven flow of the test liquid was recorded by the phone camera. After the imaging reconstruction of the flow velocity in the horizontal capillary and the capillary head in the vertical direction, a digital image processing software was developed to calculate the liquid viscosity in MATLAB 2007b environment, recurring to the established theoretical correlation for flow mechanics. To demonstrate the feasibility and accuracy of the method, 10 groups of liquid were measured and the results were compared with the data obtained from a standard rotating viscometer. The relative error was found falling in the range of 0 ~ 20 %. This study establishes a pervasive low cost way for viscosity measurement of various solutions.

Zusammenfassung:
Eine konzeptionell neue nicht-Kontakt-Methode zur Messung der Viskosität einer Flüssigkeit in einer Kapillarströmung unter Verwendung eines Mobiltelefons zur Datengewinnung wird vorgeschlagen. Video und Bilder der durch die Kapillarkräfte getriebenen Strömung der Untersuchungssubstanz werden durch die Kamera des Mobiltelefons aufgenommen. Nach der Bildrekonstruktion der Fließgeschwindigkeit in dem horizontalen und dem vertikalen Kapillarkopf, wird eine digitale Bildverarbeitungssoftware für eine MATLAB 2007b-Umgebung verwendet, um die Viskosität der Untersuchungssubstanz zu berechnen. Dabei werden die etablierten Korrelationsmethoden der Strömungsmechanik angewandt. Um die Durchführbarkeit und die Genauigkeit der Methode darzulegen, wird die Viskosität von 10 Testsubstanzen gemessen und mit den Resultaten von konventionellen Rotationsrheometern verglichen. Die relative Abweichung lag im Bereich von 0 ~ 20 %. Diese Arbeit stellt eine überzeugende, kostengünstige Methode für Viskositätsmessungen verschiedener Lösungen dar.

Résumé:
Une nouvelle méthode conceptuellement sans contact pour la mesure de la viscosité de liquide dans un tube capillaire en utilisant un téléphone mobile comme un moyen d'acquisition de données est proposée. La vidéo et l'image de l'écoulement du liquide induit par la force capillaire sont enregistrées para la caméra du téléphone. Après la reconstruction de la vitesse d'écoulement dans le capillaire horizontal et dans la tête du capillaire dans la direction verticale, un programme de traitement d'image digitale a été développé afin de calculer la viscosité du liquide dans un environnement MATLAB 2007b, en recourant à la corrélation théorique établie pour la mécanique des fluides. Pour démontrer la faisabilité et la précision de la méthode, 10 groupes de liquide ont été mesurés et les résultats cpomparés avec les données obtenues à l'aide un viscosimètre rotationnel standard. L'erreur relative se trouve dans la gamme 0 ~ 20 %. Cette étude établit une manière versatile bon marché pour la mesure de la viscosité de solutions variées.

Key words: mobile phone, non-contact measurement, liquid viscosity, image processing

1 INTRODUCTION

Viscosity is an intrinsic property of a fluid caused by friction between its own molecules layer while flowing. It would not only offer a decisive effect on the motion characteristics of the fluid, but also affects its application scopes. As a result, quickly and accurately understanding the physical feature of a fluid has always been an important target [1]. So far, the viscometers, the instrument used to measure the viscosity can generally be grouped into three broad categories [1, 2]: capillary tube viscometers [3], rotating viscometers [4], and falling ball viscometers [5]. However, structures for these conventional viscometers are generally complex and their operations appear somewhat difficult, which may significantly restrict their applications.

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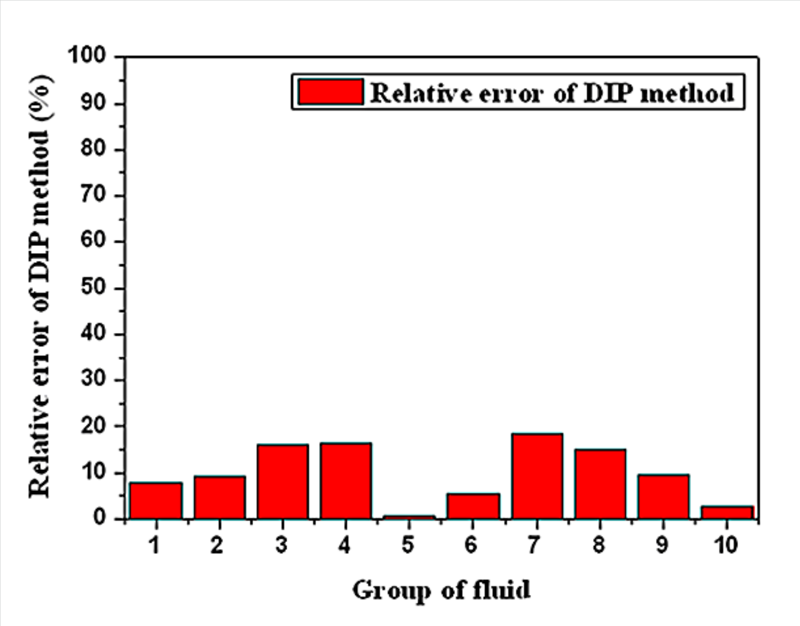

Figure 4: Relative errors for viscosity results of 10 groups liquid measured by DIP method compared to Brookfield DV-II+ Pro rotating viscometer.

Table 2 (above): Viscosity results of 10 groups of liquid measured by Brookfield DV-II+ Pro rotating viscometer.

Table 3: Measuring results of all the parameters in the experiment for the 1 % Sucrose solution.

viscometer sample cup, which was maintained at a constant temperature of 23°C by a water bath. Three tests on each kind of liquid were realized and the results listed in Table 2 were found ranging from 1.01 to 28.5 · 10^{-3} Pa·s. Comparing the above two Tables it is obvious that the results deduced from DIP methods are basically consistent with the commercially available rotating viscometer. If the measured value from viscometer is considered as the standard viscosity, the relative errors for DIP method, which mainly fell in the range from 0 to 20 % can be expected reasonable (Figure 4).

As mentioned before, the capillary tube length L, inside diameter a and the test liquid density ρ are obtained by the physical measurement. The capillary head h and the mean velocity v are DIP results. Then, the viscosity μ is calculated by all the above parameters. Based on Equation 5, the relative error transfer function of the system is deduced as:

$$\frac{\Delta\mu}{\mu} = \pm\left(\frac{2\Delta a}{a} + \frac{\Delta\rho}{\rho} + \frac{\Delta h}{h} + \frac{\Delta L}{L} + \frac{\Delta v}{v}\right) \qquad (6)$$

where Δ represent the absolute error to the average value. For the 1 % Sucrose solution, the values of above parameters in five tests, corresponding with the absolute and relative error, are listed in Table 3. According to Equation 6 it can be calculated that the relative error transfer is $\Delta\mu/\mu = \pm\ 0.328$. Therefore, for the average value μ = 1.0875 · 10^{-3} Pa·s of the viscosity the absolute error transfer is $\Delta\mu = \pm\ 0.357 \cdot 10^{-3}$ Pa·s. Considering all 5 variables, the inside diameter of the tube was the primary cause of the error transfer due to the factor "2". Besides, when acquiring video and image data we calculated the length to pixel ratio approximately by keeping the camera visual field fixed simply instead of complicated camera calibration, which might also have increased the error.

Group	Liquid		Viscosity (10^{-3} Pa·s)			Average viscosity (10^{-3}Pa·s)
1	Sucrose solution	1%	1.09	1.00	0.93	1.01
2		5%	0.98	1.13	1.09	1.07
3		10%	1.26	1.10	1.18	1.18
4		20%	1.53	1.52	1.50	1.52
5		50%	4.20	4.06	4.05	4.10
6	Glycerol aqueous solution	1:1	5.41	5.40	5.35	5.39
7		2:1	11.1	11.0	11.0	11.0
8		3:1	16.3	16.1	15.5	16.0
9		4:1	21.9	22.2	20.8	21.6
10		5:1	28.4	28.3	28.7	28.5

Variables	Measuring results					Average value	Absolute error	Relative error
L (mm)	96.7	96.5	96.5	96.3	96.5	96.5	0.02	2.07E-4
D=2a (mm)	0.50	0.45	0.46	0.44	0.45	0.46	0.04	8.70E-2
ρ (g/ml)	1.0030	1.0042	1.0028	1.0038	1.0032	1.0034	0.0008	7.97E-4
h (mm)	46.60	49.74	47.76	44.56	48.97	47.53	2.97	6.25E-2
v (mm/s)	30.16	32.17	28.38	28.38	28.38	29.49	2.68	9.09E-2

4 DISCUSSION

In many situations such as field work and point-of-care in clinics, a quick and low cost viscosity measurement is often required. The present method is provided with evident merits over conventional strategies. The liquid density can be acquired by use of table look-up or simple operations easily. Liquids with viscosity from 1.01 · 10^{-3} Pa·s up to 28.5 · 10^{-3} Pa·s are suitable to be measured by this method according to the experiments. It provides a convenient tool for rough measuring and estimating viscosity range. Moreover, this method does not require contacting with the liquid, so the external interference is completely avoided.

The experiments and analysis as given above revealed that the relative error was acceptable (0 ~ 20 %). Besides, there were several factors affecting the results and increasing the error. First, according to data analysis a was the main cause of error transfer. However, the consistency of capillary tube inner diameter a used in the experiments was less than perfect. Second, com-

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plicated camera calibration was not carried out to compute the actual dimensions. The simple comparison between pixels number and measured dimension would offer some effects on the height of the vertical liquid column *h* and mean velocity of the liquid in horizontal tube v. Therefore, by using capillary tubes with more accurate inside diameter and more precise camera calibration, it is possible for one to reduce the error to some degree.

The digital image processing program was developed in MATLAB owing to its powerful image processing functions. Restricted by the capacity of CPU, we compressed video data to 160 x 120 and adjusted video processing step to reduce time cost. However, the compressed video data to the low resolution might influence the measured result in a lesser extent. Additionally, with the technology development, the data processing capability of the smart phone will be provided with a dramatic increase in the near future, which means the video compression is no longer needed and the DIP program can be run in the phone-self. This would provide a low cost, pervasive and more convenient approach for viscosity measurement.

In order to achieve the precise measurement, all test liquids are dyed by quantitative neutral red to enhance the contrast to the background. In the actual practice, if the test liquid is colored, such as blood, the background should be set as a high contrast to the test liquid; if the test liquid is clear and colorless, the air-liquid interface cannot be recognized automatically by the DIP method. Therefore, the dyeing pretreatment is inevitable for the measurement. Besides, to only track the main area of liquid flow can reduce the data amount processed by computer, which is not involved in our program as an optimization method yet.

5 CONCLUSIONS

This study introduced a new method for measuring liquid viscosity by employing the common cell phone and computer. Compared to the conventional methods, it is not restrained by the location and massive procedure, and is capable of being rapidly implemented. This makes the measurement rather practical. Comparing the results with a standard viscometer, the feasibility and accuracy of the new viscosity measurement technique have been demonstrated for several typical liquids with different viscosity. Among the advantages of this new method are simplicity, low cost, and good practical value.

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