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Multiparameter analysis of optical technique used for newtonian fluid viscosity

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Abstract

Presents work mainly deals with a technique based on optical tracking of the free fall in a Newtonian fluid used in falling ball viscometers. Classical techniques have shown, on one hand a limit in the ball falling height measurement, on the other hand a limit in the accuracy estimation of velocity and therefore a weak precision on the viscosity calculation of the fluids. Our method consists to measure the fall height by taking video scenes of the ball during its fall and thus to estimate its terminal velocity which is a preponderant parameter in the kinematic velocity computing, using both the Stokes or Hoppler formalisms. The prerision reached in this approach adjoins encouraging values for future works in the purpose to improve this method further.

Keywords: Optical, newtonian, viscosity, fluid, stokes

Introduction

Viscosity is known as a material (fluid) resistant to the movement under shear stress action, and it characterizes its suitability to flow under forces such as gravity. It is due to the friction between neighboring particles in a fluid that are moving at different velocities [1, 16]. When the fluid is forced through a tube, the fluid generally moves faster near the axis and slowly near the walls. Therefore, some stress (such as a pressure difference between the two ends of the tube) is provided by the gravity forces and is needed to overcome the friction between layers and to keep the fluid moving. For the same velocity pattern, the stress required is proportional to the fluid's viscosity. Because studying a flow of viscous matter is sometimes fastidious and requires complicated dispositive, we can as the movement is relative in Eulerian reference change the stream, otherwise, instead to force the fluid to move, make the obstacle moving around the fluid and then study its movement using Navier Stokes equations and fluid kinematic formalism. That is why many viscosity measurements based on Stokes or Hoppler [2, 10] methods take in consideration a falling ball within a cylinder tube full by the studied substance, and estimate its terminal velocity indispensable for the above cited methods to compute the kinematic viscouty in mm²/s. The novelty in this thesis is the technique by which the distance browsed by the falling ball is estimated relief of optical tracking, based on video capture of movement.

Materials and Methods

In order to perform the experimentation, a set of balls of different diameters made of different materials. (Steel, Altuglass PMMA and Wood) is used. Every material has its proper characteristics such as density, and viscous friction factor given by the Stokes lawask 3D, where D is the ball diameter [3, 5]. These parters determine the ball behavior in the fluid and are relevant for the viscosity calculation accuracy using the most famous two models adopted in this work. Two industrial and vegetal fluids in different temperatures varying by the step of 20 °C (range of 19.7 to 98.6 ^{0}C rangle are tested [15]. We retain that fluids in this work are Newtonian and transparent for the need of optical aspect of the measures which request a digital high-quality camera and high visibility of the ball in its fall within the translucent tub. Placed in front of the tube using an adequate system which allow good lightening and good object plan distance, the camera is synchronized with the beginning of the fall. Lightening conditions are crucial for the visibility and the quality of images to be treated in order to avoid artifacts which can blemish. the results in order to have necessary contrast needed. in the images preprocessing phase. Finally, a synchronous timing between ball release and video capture launching is ensured for good estimation of the fall height.

Data processing: The fluid flow phenomena around the ball is governed by Navier-Stokes equation for laminar regime as follows

$$\rho \frac{\partial v}{\partial T} - \nabla\eta.(\nabla V + (\nabla V)^T) + \rho v.\nabla v + \nabla p = F, \qquad (1)$$

$$\nabla\ .v\ =\ 0 \qquad (2)$$

in which ρ is the density of fluid, η its viscosity in Ns / m^2 the velocity in m/s and *p* the pressure in Pa. The model utilizes the Lagrangian acceleration referential bound to the ball, the density of the volume force is F and its radial and vertical components are respectively,

$$F_r = 0 \qquad (3)$$

$$F_z = -\rho(a+g) \quad (4)$$

where g is the earth gravitation and the acceleration of the ball in the fluid. The differential equation of movement is

$$m\ddot{x} = F_g + F_z \quad (5)$$

Because the set of balls used in the experimentation comport a ball which has a rough surface, we have observed that its downward movement has a vortex (rotation) behavior, that is why a correction factor based on rotational term where we deduct the velocity bias has been implemented in Equation 1 as follows.

$$\vec{\omega} = -\mathrm{rot}(\vec{v}) \qquad (6)$$

where ω is the rotation of the ball due to the roughness? The roughness factor Rg as we will see below is responsible for the accuracy of the results since it affects the viscous friction coefficient & and thus the viscous fric-tion force F (F_{fr}). The force balance acting on the ball has as a component a friction force given by

$$F_{fr} = -k\eta v \qquad (7)$$

This correction improves considerably the accuracy of the viscosity calculation; in our case it was improved about twenty times [4, 15]. For every experiment, video scenes of ball falling the tube in "avi" prime prime format are token and subsequently processed. Because of the size of videos (typically about 10 Mo) much CPU time and large memory was required; compression has bein neccessary by utilization of a software called Videolab integrated in C++language. Using this software allowed for the compression of the video sequences up to a factor 100, their loading and processing became therefore easier and faster.

The ball in its falling is tracked image by image, gotten an image every laps of time used to compute the instantaneous velocity v_j, a test is implemented in the source code in order to know if the movement reached its uniform phase (steady state regime) at this moment the terminal velocity v_L, is equivalent to the instantaneous velocity computed as the ratio of the browsed distance I and the time t_i,. The whole algorithm will be detailed in ulterior paragraph by flowchart implemented in the program. The cylinder tube is made of glass, has radius R and the radius of the balls r, in Stokes formula the ratio R is a parameter which affects the values of viscosibes [5]. This algorithm is implemented in C++ program where we elaborate an interface allowing the choice of the video scene and even different parameters of the experiment and then launching the calculation. We can vary the temperatures regarding the scene to process and the different parameters chosen previously. In the software interface elaborated by the way in C++ language, we can choose parameters of experiment which are the fluid nature (density), the friction factor, the material of the ball and its radius and the temperature from the Access integrated database [6].

Results and Discussion

Combination of all parameters quoted above allows us to get a precise idea about the most adequate condition for a precise determination of fluid's dynamic viscosity denoted by 'optical viscosities' in this work (because determined by video capture of ball movement). As a validation step, we compare the optical values with viscosities given by a series of manipulations on the Couette viscometer VT550 provided to us by the LAAR Laboratory.

Velocity depending on fluid density: As we see in the snapshot, the density of the fluid affects considerably the terminal velocity, for example the one for vegetal oil exhibiting the lowest density. The velocity is equal to 1.2 m/s for the test using the steel ball with diameter of 17 mm, this value is the highest value for the experimentation performed in this work. The fluid with lowest viscosity (vegetal oil) has the highest terminal velocity as we can see in the graph above, contrarily, in the industrial high viscosity oil SAE140, this velocity increases, since the vis cous force acts negatively on the movement and tends to break it. The asperity present in the curves signals that the ball undergoes a fluctuation in its movement due to the vortex's movement induced by the rough ness. That is why we have introduced the correction term. The highest terminal velocity is reached for vegetal oil using the steel ball for the highest temperature of 98.6°C which mean in this case that the viscosity is lower possible because all parameters (weak roughness, high weight) are gathered for fast fall of the ball as it shown by dashed line in the above chart. We denote also that we cannot interminably increase the diameter of the ball in order to obtain fast fall like it has been explained previously, due to Archimedes thrust.

Influence of the ball roughness on terminal velocity: The influence of the ball surface roughness on the value of limit velocity is well illustrated. This effect is due to roughness dependent friction [7] and is taken into account in the velocity calculation as follows $v=v_L$ [1-exp(-kt/m)]. When k is large enough, t reaches a sufficiently large value while m is an adequate ball mass and the quantity between parentheses tend to unity. Thus, the speed approaches the terminal velocity v_L. The graphs above show that the velocity is inversely proportional to the roughness and proportional to the diameter [8]. For example, the velocity is about 1.02 m/s for a roughness Rg = 0.063, diame ter D25 mm, because if the diameter increases the volume and the weight of the ball increase as well, so that the force of gravitation give rise to a fall it high velocity [9]. However, this augmentation cannot be indefinitely since a high diameter increases the contact surface and also the thrust of Archimedes [2] which is a resistant force and thus decrease the velocity. Contrarily the roughnesses of the ball surface means more contact surface between the ball and the fluid. Thus, the resistant friction force increases leading to a decrease of the velocity.

Effects on the viscosity accuracy: We present an exhaustive comparison between the dynamic viscosities computed by the optical method and those given by manipulation of "Couette" viscometer cited in the previous paragraph. The comparison is carried out by computing relative errors as following: Err% = (Opt_{visc}-$VT550_{visc}/VT550_{visc}$) where Opt_{visc} is the dynamic viscosity estimated optically, $VT550_{visc}$ those measured by the viscometer. Kinematic viscosity is the ratio of the dynamic by the volumic mass (density) of the fluids, it is known that density is not affected considerably by the temperature's variation. That is when it is identical to use kinematic or dynamic viscosities when comparing the different cases. The parameters of the calculation in the software, the different obtained errors vary in the best case between 0.039 and 2.81% (uncertainty equal 0.5 to 2.0% for the commercial ball fall viscometer) [13]. This means that we have obtained good accuracies. essentially due to an implementation of a robust algorithm Obviously as it is shown in the graph below, for a high viscous fluid the most adequate material for good experience conditions is steel due to its low roughness surface unless the diameter does not increase and increasing the weight with [10]. If we consider a weak condition of optical experimentation, we can easily confirm that the opted algorithm permit the elimination of the bias which blemish the results. The so mentioned conditions are a speed of the camera reaching about 30 fps which is not highly suitable to take whole video sequence of fast ball drop within low viscous liquid, and also bad lightening refraction on the tub causing artifact over processed images [11].

Representation of errors between optical and experimental viscosities: As it is shown below, the comparative study exploits the relative errors between the proposed method dynamic viscosities and those given by the viscometer. The accuracy depends on experience because we can estimate the values of the fluid's viscosities in several ways but we never have a clear idea about how much. these values make sense if we do not compare them with real values measured by a calibrated viscometer in our case the VT550 Thermo-Haake. The curves below explain well the variation of precision regarding the experimental parameters such as the diameters of the balls, the material which mean different friction factors K between the ball and the fluid, and the temperatures of the fluids which affect its viscosity with inverse proportion. The optical method adopted in this work is based on picture capture of the movement, it was remarked that the fluid with high viscosity (SAE140) is most adequate because the ball drop takes more time and thus leaves the camera time to take the whole scene.

The speed of the drop is tributary to the speed of the fall is dependent on ball diameter and roughness that tends to slow the ball in his fall and the value of the fluid viscosity since the viscous frictions are a braking force according to the force balance equations 2.3 and 2.5. Relatively to these results we can conclude that the accuracy could be improved considerably if we do a judicious choice of experience parameters but show also the limit of the method which is restricted for the Newtonian fluids with transparency aspect (no colloidal and suspension liquids) with relatively high viscosity. The results inform us that the diameter has an important effect over the uncertainties, so that if the diameter increases, the uncertainty decreases with but not indefinably since for limiting values of diameter (15.8 mm) the uncertainty reaches a regular threshold of approximately 0.2% for the lowest temperature 19.7°C and 1.8% for the highest temperature 98.6 °C.

Conclusions

As a result of this study, we can conclude that the best values for relative uncertainty are given by the mast viscous fluid SAE140. That is due to the relative low speed of the fall which allow to the optical system to take picture adequately. Also, the best material of the ball is steel, with the condition that its roughness is low and its diameter too. Globally, we can say that the optical way to estimate the height of fall and thus the terminal velocity v, has done its proof, in waiting other best improvement to get it best performance. The choice of C++ language is due to its best performance in image processing, its high precision in computing allowed to use when the values are very small like 1016 for example and its capability to create a strong and easy interface. It is clear that this method albeit its good results, has its limit and its dependencies on a drastic choice of experimental parameters and rigorous use of mathematical formalism which govern the flow and viscosity assessment. A task which is not always obvious, but at least it opens a horizon to improve an innovative method for physical parameter measurements. Following this work, we can confirm that there is an alternative method to measure experimentally the ball drop in a liquid in order to estimate its viscosity instead than previous manual methods. In any way the method presented in this thesis even it was surrounded by various difficulties such as the artifact bias generated by the light reflection in the tube glass which gave the blemish image in binning process step, also the irregular drop of the balls within the fluids which mean a rotational effect on the movement affecting the fall velocity by 0.05% it done its proof. However, this technique remains limited because it can treat only the Newtonian transparent fluids, the accuracy is closely tributary of the liquid viscosity which must be relatively high unless we use very fast shooting camera. Nevertheless, we have learned something by combining various parameters and by seeing their interoperability and effects each together and can thus get the best of their variation for improving simultaneously the procedure, the algorithm and finally the calculation precision of fluid viscosity assessment. We conclude in this contribution that multipara meter assessment of fluid viscosity by experimental way could be performed accurately under the condition that the processing takes in consideration all aspects that affect the result in order to avoid calculation errors and eliminate bias. The study seems to confirm that developing an alternative method substituting the manual classical ways of physical measures has some future; especially those that we call non-intrusive ones based on the optical approach.

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