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NEW METHOD TO DETERMINE THE VIRTUAL MASS COEFFICIENT VIRTUALLY FOR SOLID SPHERE PASSES THROUGH NEWTONIAN AND NON-NEWTONIAN LIQUIDS IN HYDROPHOBIC CASE

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ABSTRACT

A new Method is presented to calculate the virtual mass coefficient for solid sphere entering water as Newtonian liquid and Carboxy Methyl Cellulose CMC and Poly Vinyl Alcohol PVA as non-Newtonian liquids with air cavity (hydrophobic entry). The sphere's motion is recorded using high speed digital camera (1000 frame/s). The virtual mass coefficient is calculated virtually by measuring the cavity surface area part that covering the sphere' surface to the immersed part with liquid so the values of C_{VM} varies between (0.25-0.5).

In this method, the shape of square is drawn on transparent paper to put it on the monitor of the recorded video at the center of the moving sphere, the measuring square grades are calculated and designed to give the values of C_{VM} (0.25, 0.3, 0.35, 0.4 and 0.45), C_{VM} equals 0.5 for hydrophilic case (without cavity) when the cavity is collapsed due to liquid's drag and static liquid pressure at a certain depth that become more than air cavity pressure inside the cavity. At that instance, the sphere becomes fully immersed in liquid.

INTRODUCTION

Many scientific researchers have been published over the past seventy years about dropping solid sphere in different types of Newtonian and non-Newtonian liquids to calculate drag coefficient C_D and virtual mass coefficient C_{VM}. In environmental engineering, the predictions of solid particles settling velocity are used for modelling all particle process in water as sedimentation, flocculation, boiling, flotation and filtration.

Various methods have been used for recording sphere's motion. During the development of modern technology, high speed digital camera were used to enable recording moving sphere to see hydrophilic case as a result of entering sphere from air across water or any other liquid. May and Woodhull [1] studied the calculation of C_{VM} for solid spheres of different materials accelerated by high speed and they gave an average value of C_{VM} = 0.08 but they ignored the effect of Basset or history force from the equation of motion.Odar and Hamilton [2] modified the equation of motion for a single solid sphere (fully immersed in water) by adding C_D, C_{VM} and history force coefficient C_H and gave them as a function of Reynolds number Re in the range (0<Re<62).

Kendoush [3] theoretically computed C_{VM} = 5 for rotating sphere fully immersed in a liquid for Re<10.Mohammed [4], Al-wared [5] and Mahmood [6] adopted the results of Odar and Hamilton [2] in solving the equation of motion for single solid sphere to compute C_{VM} by assuming a C_D model, the resulted C_{VM} = f(Re) is about the theoretical value of C_{VM} = 0.5 in the case of fully immersed sphere starts motion from rest from a point just below the liquid surface (Mohammed [4] and Al-wared [5] published their results in [7] and [8] respectively), when applying the same procedure for the hydrophobic water entry i.e. the solid sphere starts motion from above liquid surface where the sphere's velocity decreased through its descend through the liquid, the values of the resulted C_{VM} varies between (-1 to -800) which is refused result because C_{VM} is real positive value related with the added mass to the solid sphere at transient motion i.e. the sphere's velocity differs from terminal velocity. May and Woodhull [1] and Truscott and Techet [9] studied the water entry of solid sphere, Truscott and Techet took a constant value for the C_{VM} 0.25 or 0.5 for hydrophobic cases and 0.5 for hydrophilic cases to determine C_D. The present study gives a new method to estimate C_{VM} virtually using the recorded video of the solid sphere for hydrophobic liquid entry case, new measuring equipment is designed to measure $C_{VM}$for different ranges of numbers between (0.25-0.5), the results of Truscott and Techet [9] are measured using the new method and a value of 0.35 is found which makes their results more accurate, and more details were given in [10].

EXPERIMENTAL PROCEDURE

Measuring equipment

The measuring equipment is shown in figure (1); the basic definition of the virtual mass coefficient is based on the ratio of the volume of the liquid that is displaced by the solid sphere to the volume of the solid sphere which is equal to 0.5 [6] which is the theoretical value for hydrophilic sphere immersed in full liquid. In the case of an air cavity (hydrophobic) the theoretical value of C_{VM} is equal to 0.25 [9]. The measuring equipment of C_{VM} is drawn on a transparent paper so it can be put on the computer screen (when the recorded video is displayed) by putting the center of the equipment on the center of the solid sphere as shown in figures (2), (3) and (4). To understand the idea see figure (1) where the equipment is divided into two equal rectangles, one is lower and the other is upper and is divided into many sections according to the angles between the horizontal center line and the upper inclined lines. When placing the center of the equipment on the center of the sphere in which the cavity is on the upper rectangle, if the cavity begins from half the outer surface area of the sphere exactly that means $C_{VM} = 0.25$ as shown in figures (2) and (3). If the cavity begins from right and left by 18˚ that means $C_{VM} = 0.3$. If the cavity begins from right and left by 36˚ that means $C_{VM} = 0.35$ as shown in figure (4). If the cavity begins from right and left by 54˚ that means $C_{VM} = 0.4$. If the cavity begins from right and left by 72˚ that means $C_{VM} = 0.45$. At the instance of cavity collapse, the $C_{VM} = 0.5$ i.e. the sphere converted from hydrophobic into hydrophilic. The values of the above angles are corresponding to the values of C_{VM} that are evaluated by dividing the volume of the wetted part of the sphere to the sphere's volume.

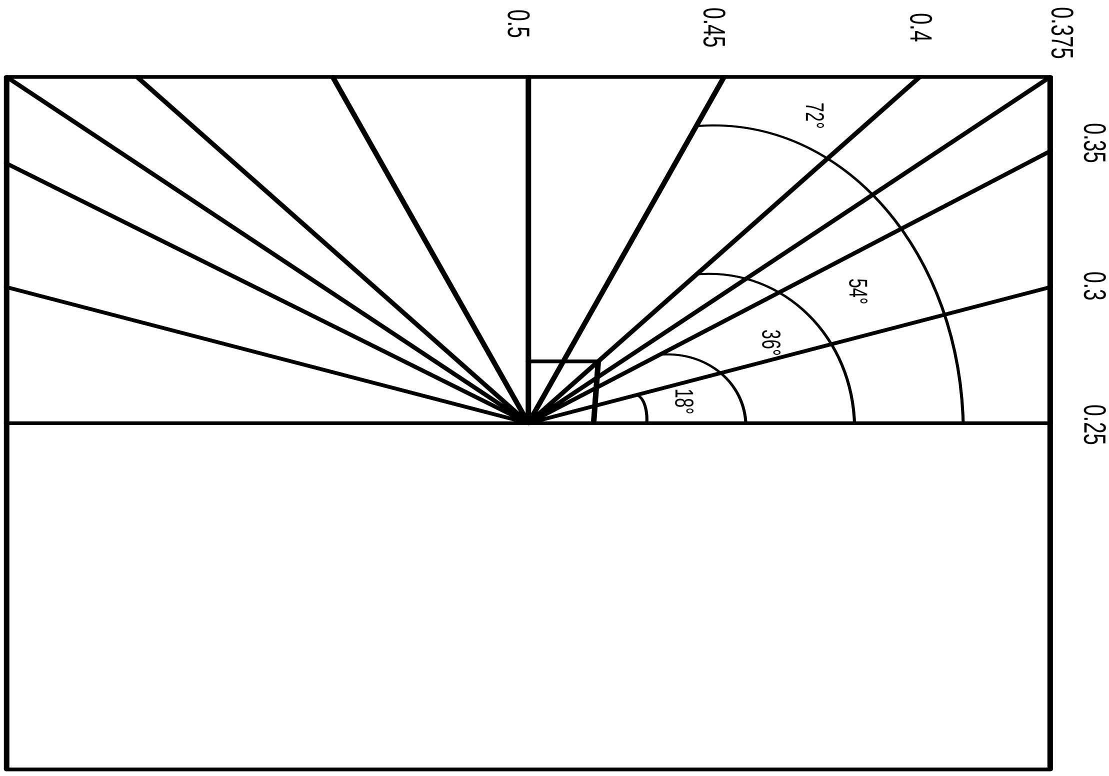

Figure 1: C_{VM} measuring equipment diagram [10].

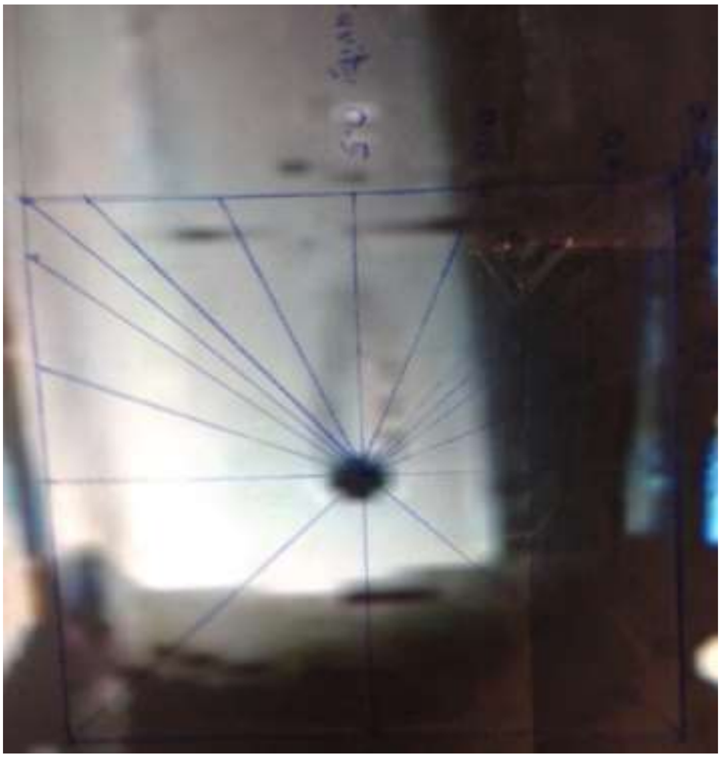

Figure 2: Direct measurement of C_{VM}=0.25 for 25mm solid sphere [10].

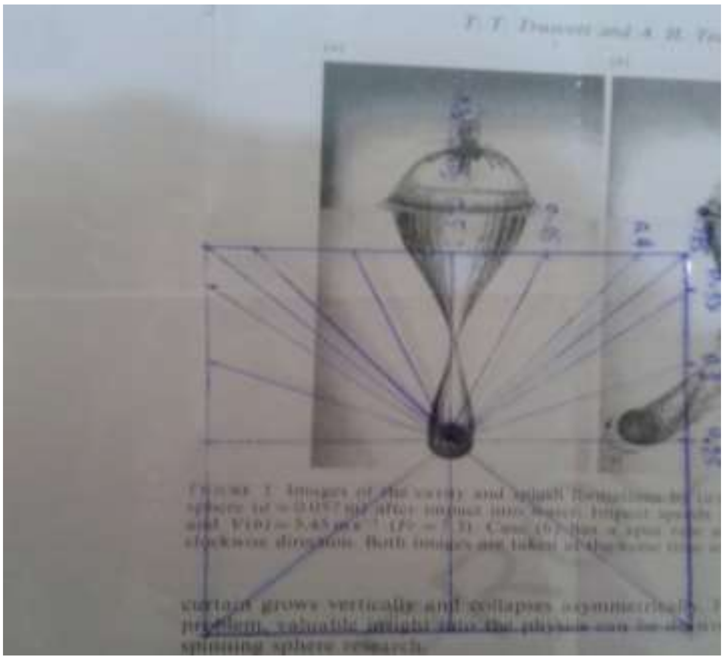

Figure (3): Direct measurement of C_{VM}=0.25 for Truscott and Techet [9].

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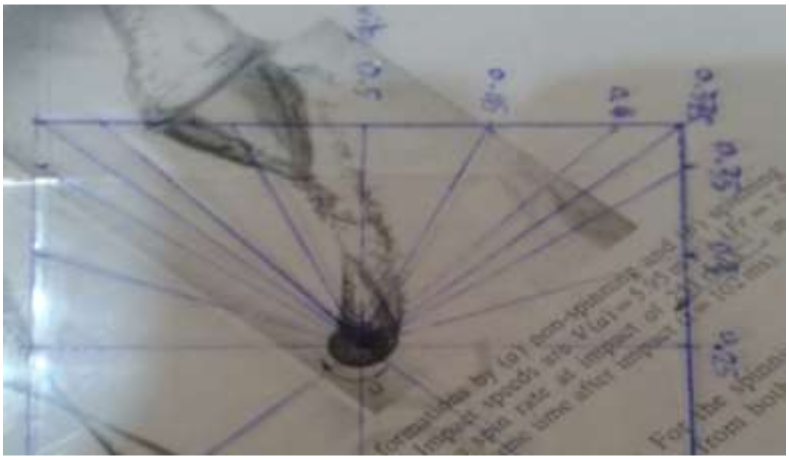

Figure (4): Direct measurement of C_{VM}=0.35 for Truscott and Techet [9].

RESULTS AND DISCUSSION

Figure (5) shows the effect of rotation on C_{VM} (S represents spin parameter which is the ratio of the product of sphere angular velocity and radius of the sphere divided by sphere linear velocity), NR refers to non-rotating case, the rotation increases C_{VM} because as shown virtually from experimental recorded videos (see figure 4 for hydrophobic cavity) that rotation makes the cavity to rotate faster and the air leakage to the liquid increases in the same time cavity volume decreases and the volume of the liquid around the sphere increases which increasing C_{VM}.

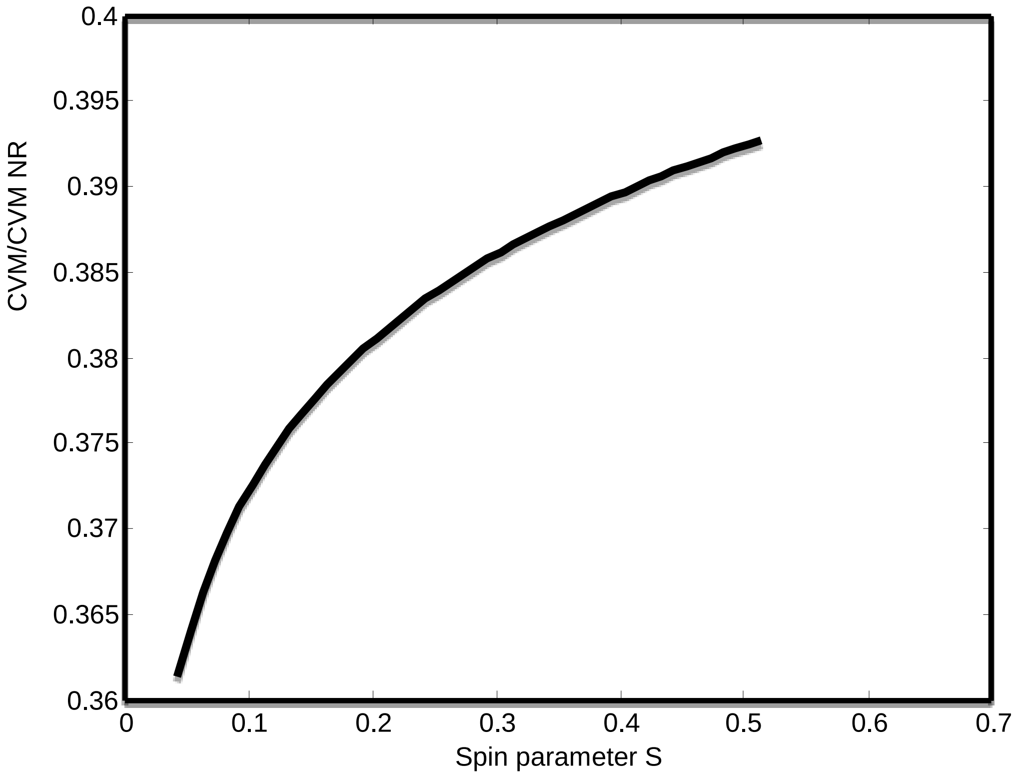

Figure 5: Effect of rotation on C_{VM} for water

For non-Newtonian liquids, the effect of rotation on C_{VM} of PVA is shown in figure (6) in which as the spin ratio increases the ratio of C_{VM}/C_{VM} (NR) decreases from (1.4195-1.416).

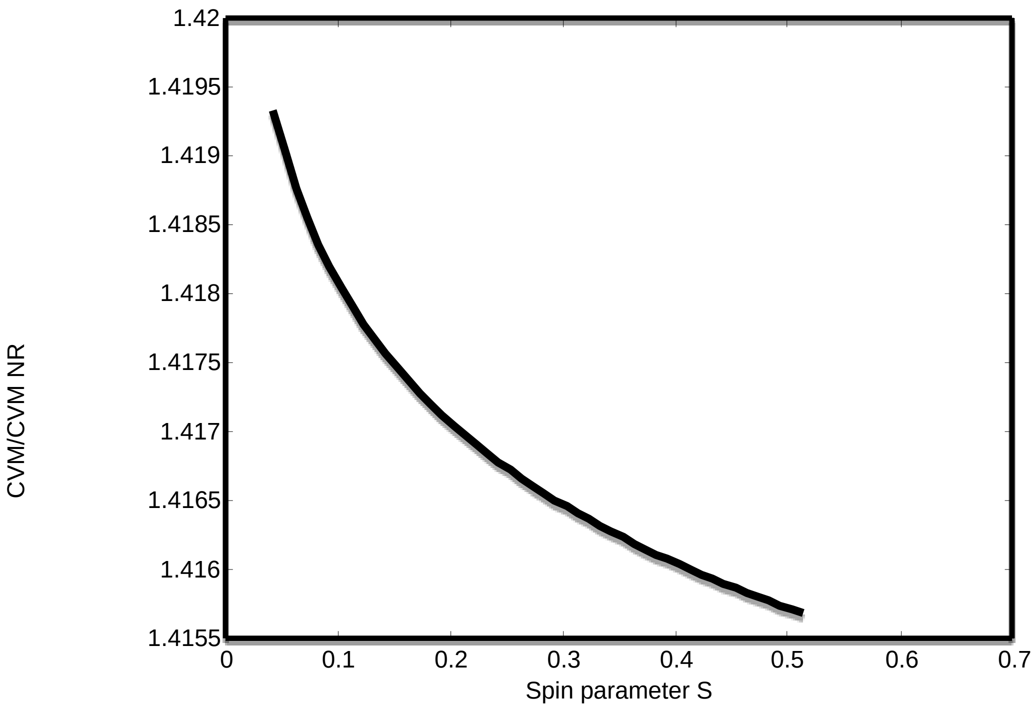

Figure 6: Effect of rotation on C_{VM} for PVA

For CMC, the effect of rotation on C_{VM} is shown in figure (7) in which as the spin ratio increases the ratio of C_{VM}/C_{VM} (NR) increases from (0.9688-0.97). From figures 6 and 7 for $S < 0.5$, the effect of rotation on C_{VM} for non-Newtonian liquids are little and can be negligible vice versa Newtonian liquids see figure 5.

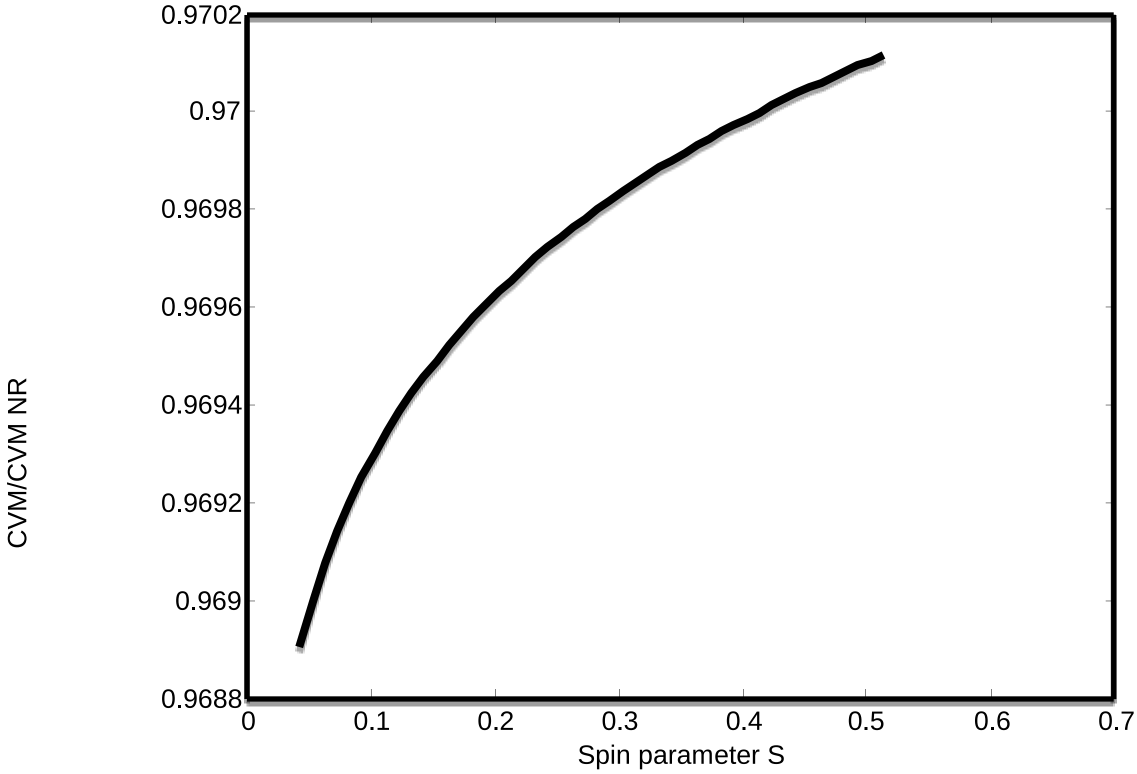

Figure 7: Effect of rotation on C_{VM} for CMC

CONCLUSION

1. The virtual mass coefficient for rotating sphere is larger than for non-rotating sphere of the same diameter, initial releasing velocity, surface roughness and liquid type**.**
2. The virtual mass coefficient for hydrophobic sphere is smaller than for hydrophilic sphere of the same diameter, initial releasing velocity, surface roughness and liquid type.
3. The effect of rotation on C_{VM} for non-Newtonian liquids can be negligible for $S < 0.5$.

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