Off Centered Impact of Water Droplets on a Thin Horizontal Wire

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Abstract

The current work focuses on the initial stage of filtering droplets, and explores the influential factors of drops impacting on a thin horizontal dry wire. We investigate the effect of the impact velocity, wire thickness, initial drop size and liquid surface tension along with the impact eccentricity, i.e. the distance between the trajectory of the drop and the axis of the wire, on the amount of liquid trapped on a wire.

It was found that for high impact velocities (1.35, 1.41 m/s), the amount of liquid that remains on the wire is minimal and is fairly constant. For low and medium velocities (0.46-1.25 m/s), the amount of liquid that remains on the wire increases at a critical eccentricity value (from 0.2 to 2 mg), and from there it decreases. As the velocity increases, the maximum amount of liquid captured on the wire decreases while the corresponding critical eccentricity increases. This behavior was first observed and explained by Lorenceau et al. [5]. For a centered impact, the droplet is divided into two independent fragments, where each volume is bigger than the critical cature volume [5]. These fragments do not remain on the wire, and are detached under the effect of gravity and inertia. Only a small fraction of liquid remains on the wire in this case, following coating theorems. As the eccentricity increases, less equal the two lobes become, till the volume of one of them get smaller than the critical volume, consequently, it remains on the wire under the effects of the capillarity and friction that keep it from falling. An additional increment of the eccentricity above the critical value results a decrease of the captured fragment, till it extinct at e~R.

These findings led to a development of a criterion that characterizes the amount of liquid that can be captured by a wire. The criterion is based on a force balance and includes 4 non-dimensional (Re, We, Fr and the wire-drop radii ratio). The critical eccentricity and the max amount of captured liquid have been calculated and compared with experimental observations. A good agreement was found. Therefore, our equation provides a reliable criterion to determine the amount of liquid captured by a wire.

Introduction

A Fiber filter is a fibers mesh that is being used to recover solid and fluid particles from aerosol. The droplets are collected by the solid part of the mesh while a gaseous phase passes through it. Its purpose is to capture as much fluid as possible on the fibers and to slow down the liquid fragment dropping from the mesh. Such meshes are used as fog's nets to recover liquid from morning fog in a deserted area [1]. These meshes are also commonly used in chemical plants for impurity removal and to prevent liquid pollutant from slurries to be emitted to the atmosphere.

This work focuses on the drop impact at the initial stage of filtration, the stage of maximum efficiency [2], when the filter is still dry. The filter qualities at this stage, depend on different length scales: the typical distance between the fibers of the net, λ, the mean radius of the aerosol droplets, R_i, and the fiber radius, b. By taking the case where the typical distance between the fibers is much bigger than the fiber diameter (λ>>b), we restrict the investigation of the first step of the filtration, on the comprehension of a drop impact on a single fiber.

Several studies have been devoted to droplets impacting cylinder geometry, but first it is requisite to address the static problem, and to introduce the definition of **capillary length** which is defined in Lorenceau, Senden and Quéré [3] work as the length for which the surface tension and gravity balance each other. This balance produced the definition:

$$k^{-1} = \sqrt{\sigma / \rho g} \qquad (1)$$

, denoting ρ and γ as the liquid density and surface tension.

Lorenceau, Clanet and Quéré [4] examined the static and dynamic conditions for a drop to hang on a horizontal nylon fiber. They defined the critical radius of a hanging, R_M, which is the maximum size of static drop, hanging on horizontal fiber. Any drop larger then it would detach the fiber. When the cylinder fiber radius is larger than the capillary length, the critical radius of a hanging is aspire to a constant value of:

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$$R_M \sim 1.6k^{-1} \tag{2}$$

In this case, the drop film curvature is very low and the liquid behaves as it is hanging from a flat surface, so the capillary length becomes the only length in the system as was stated by Boucher & Evans [5]. Lorenceau results are also consistent with Padday& Pitt [6] numerical calculation.

In the case of thin fibers, i.e. when the cylinder fiber radius is smaller than the capillary length, as in our experiments, the threshold radius above which a drop pending from a horizontal thin fiber will detach, is also depends on the fibre radius according to:

$$R_M = 3^{1/3} b^{1/3} k^{-2/3} \tag{3}$$

, denoting b as the fiber radius. According to Lorenceau, the radius of the largest drop hanging from horizontal thin fiber is the same as the critical radius of hanging from perpendicular needle (Tate's law [7]), with a difference of factor 2 for horizontal fiber, which implies that the threshold drop pending from a fibre is larger if the fibre is horizontal than if it is vertical.

Lorenceau also modelled the problem of a large drop hanging on a horizontal thin fibre by assuming that the force resulting from the horizontal fibre is equivalent to the force generated by two similar fibres connected to the drop at the same location, yet pointing radially (see description at **Figure 8**). Following this model, the total force acting upwards against the gravity is: $F_c=4\pi b\sigma\cos(\pi/2-\alpha)$.

Nevertheless, since this work investigates the dynamics of a falling drop, viscous and inertia effects should be taken in consideration, in addition to gravity and surface tension. Gravity and inertia force the drop cross and detach the fiber while surface tension helps to keep the drop on the fiber, and viscosity effects absorb the kinetic energy and might stop the drop. For drops with radius smaller than R_M, which can stand at rest on a fibre, a critical velocity of capturing the drop on a thin fiber, V*, has been also been defined by Lorenceau et al.. The **critical velocity of capture**, above which a drop of radius $R<R_M$ cannot be captured by the fiber, is also affected by the drop and the fiber sizes. It decreases with increased drop radius, which means that large drops are less likely to be captured than small ones. This behaviour becomes crucial as R approaches R_M, at which point the critical velocity approaches zero. Moreover, for a given drop the critical velocity is bigger if the fiber is thicker.

Hung and Yao [8] also investigated photographs of impact of water drops on wires, focusing on the modification of the impacting drop. They classified the phenomena by two modes of impaction: disintegration and dripping. The disintegration mode occurs when the drop diameter is larger than the wire ($R_i>b$) or at very high impact velocity due to high inertia and low contact between the drop and the wire that causes a reduced surface tension effect. The phenomena of drops dripping from the wire occurs due to momentum or gravity effects, primarily when the wire is larger than the droplet size ($R_i<b$). In most of their experiments, a continuous stream of droplets that impacts the wire has been used, rather than a single drop and their analysis mainly refers to the cases where the drop diameter is smaller than the wire**.** They have also examined the surface tension effect by using wax wires, and observed that drops dripping from these wires are smaller than the ones from the non-waxes wires, due to reduced lower tension effect.

The studies mentioned above were examined while the center of gravity of the drop was coordinated with the fiber horizontal axis. Very limited published literature is available on the off-centered impact of a drop on a horizontal wire, an impact with offset between the drop trajectory and the tube axis as described in **Figure 1**.

Pasandideh, Bussmann, Chandra and Mostaghimi [9] have developed a numerical model of droplet impact on horizontal cylindrical substrate and simulated it for two cases, one where the drop size is larger than the wire, and second is for the opposite case. Their simulations were done for centered and off-centered impact. According to their simulations, in the case of large drop falling on a thin wire, the falling liquid column after the impact becomes unstable and brakes-up as it descends. The offset between the drop trajectory and the wire axis affects the number of the droplets formed as a result of the impact.

Lorenceau,Clanet, Quéré and Vignes [10] have examined the effect of off-centered impact on the amount of fluid captured on a wire at velocities higher than the critical velocity of centered impact. After analyzing high speed photographs, they concluded that centered impact, in which the drop trajectory and the wire axis intersect, is not the ideal condition for capturing maximum amount of liquid on the wire. The amount of liquid captured on the wire is a function of the impact velocity and the **eccentricity**, i.e. the distance between the center of mass of the drop and the wire axis (marked in **Figure 1** by the letter **e**). Lorenceau et al. (5) have reported two coexisting branches, low and high, to which the data values of the amount of captured liquid, can collapse to. The first branch exists at low and medium eccentricity values. On this branch the amount of fluid that remains on the wire after the impact is low and constant. Only a small fraction of liquid remains on the wire in this case, following coating theorems. On the other branch, which exists for medium and high eccentricity values, the amount of liquid trapped on the wire is higher but significantly reduced when increasing the eccentricity. The explanation to this behaviour will be displayed later on on at the results section.

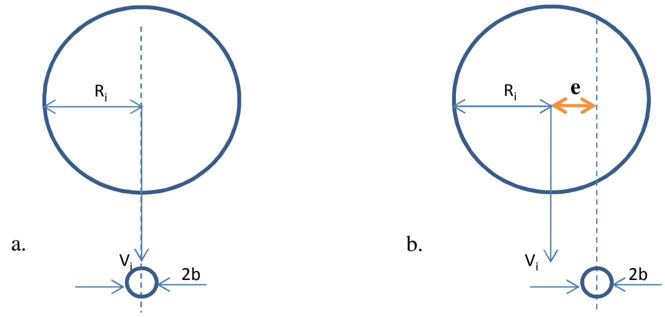

Figure 1: Sketch of a liquid drop of radius Ri that impacts a horizontal wire of radius b<Ri with a velocity of Vi (a) at centered impact (b) at off-centered impact, where the distance between the trajectory of drop center of mass and the wire axis is the impact eccentricity, **e**.

As can be seen, most of the experimental studies have been based on photographs analysis of liquid droplets falling on a wire. The current work investigates how the amount of liquid trapped on wire is affected by the eccentricity along with the impact velocity, initial drop size, wire thickness and the liquid surface tension, using statistical analysis of the weight of the drop before and after the impact. Because in filtration applications the drop diameter is usually larger than the fiber, we will focus on the case of thin wire with diameter which is smaller than the capillary length ($2b<k^{-1}$). Our statistical analysis results will be added to the image analysis that have been presented in previous works and this will allow us to deepen the understanding of the effect of surface tension, gravity and inertia on the mechanism of drop impacting a thin horizontal wire.

Experimental Method

Sets of Experiments were performed in order determine the amount of liquid that remains on a wire after a drop impact. The experimental set up consisted from a distilled water droplet dripping on a horizontal stainless steel wire, at a room temperature. The water droplet was made by a dropper connected through a tube to a needle and measured by analytical scales, with a precision of 0.1 mg, placed under a wire. The impact velocity was controlled by changing the needle height above the wire, at distance that varied between 0.70±0.01 to 12.00±0.01cm, which yielded velocities in the range of 0.4 to 1.5m/s with max calculated error of ±0.003 m/s. The wire was fixed in a plane that could be moved horizontally. The movement, meaning the wire position relative to the trajectory of the drop, was measured by micrometer and a total error of ±0.05mm in eccentricity was estimated experimentally. The whole process was lit up from behind and recorded using a high speed camera with typically 1000 frames per second, providing frontal images of the impact.

For each set, N droplets were allowed to impact the wire, while measurements were taken for the uncaptured droplet fraction. In all measurements, the impact velocity was set experimentally to be larger than the critical velocity of capture at centered impact, and measurements were made for several eccentricity values. The amount of liquid that remains on the wire has been determined by comparing the average weight of the uncaptured droplet fraction to the average weight of the initial drop. The comparison was done by using Tukey statistical test, which is widely common multiple comparison procedure that is used to determine which means are different from one another. All possible pairs of means were compared with a significance level of α=0.05, using JMP software. Consequently, the confidence interval band for each calculated difference was considered to give a 95% confidence that the stated interval indeed encompasses the calculated difference of the population mean (meaning the liquid that remains on the wire) [11].

Results and Discussion

The calculated data points, which represent the mass of the captured liquid, from a ~8 mg water droplet captured by a 0.49 mm diameter stainless steel wire at different eccentricity values, e, are presented in the graphs collected in **Figure 2** for various velocities. The results show that at high velocities (1.35, 1.41 m/s) the amount of liquid that remains on a wire is minimal and fairly constant, varying only between 0.2-0.4 mg. At the highest eccentricity (1.4 mm) and velocity (1.41 m/s) the amount of captured liquid is null since the drop barely touches the wire. At low velocities (0.49- 0.90 m/s), the amount of liquid that is captured on a wire rises by one magnitude (from 0.1 to 2mg) with the increase of the eccentricity up to the **critical eccentricity** value, when it decreases. This behaviour can also be seen, though less intensely, at the higher velocities of 1.16 m/s and 1.25 m/s. At these velocities the change in the amount of liquid captured on a wire is about 0.5 mg (in the range of 0.2-0.7mg).

Similar behaviour was also observed in Lorenceau et al. [10] image analyzes [10] and was explained in their work by two independent fragments that are created during the impact. The set of images in **Figure 3** demonstrates how a drop that impacts a wire is divided into two fragments. For a centered impact, the volume of each equal in size fragment is larger than a critical volume that can be captured by a wire. Therefore these fragments do not remain on the wire, and are detached under the effects of gravity and inertia, and only a small fraction of liquid remains on the wire. **Figure 4**, where the two fragments are separated from each other when leaving the wire because of the thick wire that functions as a barrier, vividly illustrates the fragmentation into two droplets.

As the eccentricity increases, the same process occurs and the drop is divided into two fragments, though at off-centered impact the fragments are not equal. As the volume of each one of the fragments is still larger than the critical volume that can be captured on a wire, both fragments cross the wire and detach it, as has been seen in **Figure 3**b and also in Pasandideh et al. numerical simulation [9].

As the eccentricity increases even more, the less equal the two fragments become, until the volume of one of them gets smaller than a critical volume of capture. Consequently this fragment remains on the wire under the effects of capillarity and drag force that keep it from falling. According to the findings from **Figure 2**, the first eccentricity value, for which the amount of the captured liquid is significantly increased at a velocity of 0.6 m/s, is equal to e_c=0.6 mm; meaning this is the **critical eccentricity** value in which the volume of one of the fragments gets small enough to be captured by a wire. The photographs that are presented in **Figure 3**c are taken at this point.

An Additional increment of the eccentricity above the critical value results a decrease of the volume of the remaining fragment, till it extinct as the eccentricity approaches to the wire radius ($e \sim R_i$) as can been seen in **Figure 3**d.

As aforesaid, Lorenceau has suggested that all the data values of the amount of liquid that is captured by a wire can be presented by a two branches, constant-low and high. According to Lorenceau, these two branches coexist. The results that are introduced here do not suggest coexistent ranges. The low and fairly constant branch falls at eccentricity values smaller than the critical eccentricity while the upper branch is attributed to eccentricity values that are bigger than the critical eccentricity (example marked at **Figure 2** in dashed gray lines). A further look at Lorenceau et al. results reveals, that two points obtained from their analysis at a low velocity (0.49 m/s), have been associated with the lower range, even though they are seen at the area after the leap at the critical eccentricity. It can be seen that at very low velocities (meaning close to the critical velocity of capture- 0.49, 0.60 m/s), the decrease in the captured liquid mass after the leap at the critical eccentricity is quite steep. This can explain the two points of low amount of captured liquid at the low velocity, that were observed in Lorenceau work at an eccentricity value which was only slightly bigger than the critical eccentricity. These points should be attributed to the decline of captured liquid after the highest point of critical eccentricity at the upper branch (i.e. range).

Inertia Surface Tension, Drag and Gravity Effects

When the velocity increases, the inertia effect (proportional to v^2) that is causing the drop to cross and detach the wire, is established, while surface tension and viscosity effects (proportional to v) are not significantly changed. Therefore, less liquid is attached to the wire. As aforesaid, Lorenceau et al. [4] defined a critical velocity of capture above which, a drop of radius $R<R_M$ cannot be captured by a wire. This critical velocity increases as the initial drop radius decreases. Similarly to this behaviour, regarding velocities higher than the critical velocity of capture and considering the division of the falling drop into two fragments, large fragment, which resembles a large drop, can be captured only at low velocities, where the inertia is relatively low. As the velocity increases, the maximum mass of the liquid that can be captured by a wire decreases. This requires splitting into smaller fragments for capture to occur, and therefore requires also a higher eccentricity.

The whole process of splitting to two fragments, changing in size until the capture of one of them at a critical eccentricity and decreasing of the captured fragment volume above this eccentricity has been seen in all experiments that were preformed for drops in different sizes (Ri~1.1 & 2.5 mm) and for wires at different thickness (b= 0.3 & 0.8 mm). Thickening the wire was found to increase the maximum amount of the captured liquid because of the larger surface area. This means that bigger fragment can be captured by a thicker wire, since the capillary and drag effects are increased, and so, the corresponding critical eccentricity value is decreases.

The max amount of captured liquid was also increased when the initial drop radius was increased, but the **relative** amount in this case is significantly smaller (0.27 ratio for an 8 mg drop versus 0.05 for a 54 mg drop at a velocity of 0.6 m/s) since the volume of the largest fragment that can be captured by a wire almost does not change. The **relative** amount was found to be even smaller at a higher velocity (1.16 m/s) when the inertia effect becomes more significant. The corresponding critical eccentricity value, in the case of large drop is increased since the two fragments that are created during the impact are much bigger than those that are created from a smaller drop at the same eccentricity values, and therefore require an increment in the critical eccentricity so the drop will split into smaller fragments that can be captured by a wire.

Using SDS solution to decrease the liquid surface tension (from 72 mN/m to almost a half- 36 mN/m) was found to substantially reduce the max amount of captured liquid (from 1.8 mg to 0.8 mg at a velocity of 0.60 m/s) due to weak surface tension effect. On the other hand, the small amount of coating liquid that remains on the wire before the critical eccentricity is actually increases in the case of SDS solution droplets, since in the case of surfactant solution two interfaces, solid-liquid and liquid-vapour, instead of one, are responsible for the coating, as explained in Quéré review [12]. In fact, the difference between the max amount of captured liquid and the lower range, in the experiments with SDS solution, is blurred since the upper range tends to be lower than that in the case of pure water and the lower range appears higher.

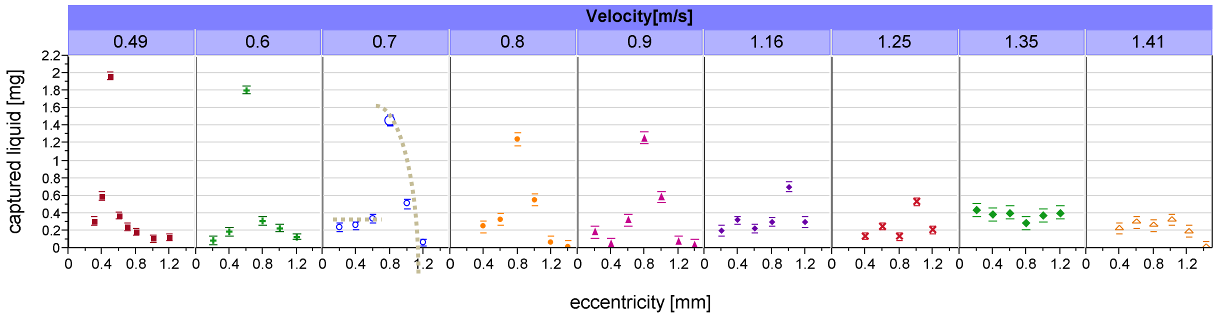

Figure 2: The mass of liquid trapped by the wire after the impact, m_w, vs. the impact eccentricity, e, for different impact velocities, which are higher than the critical velocity of capture. The wire diameter is2b=0.49mm and the drop initial radius is Ri=1.25mm. The horizontal lines are the upper and lower limits of the confidence interval range.

Figure 3: The impact of a 1.25mm radius drop on a 0.49mm diameter wire at impact velocity of 0.60m/s. **(a)** centered impact **(b)** off-centred impact of 0.4mm **(c)** off-centered impact of 0.6mm (the critical eccentricity) **(d)** centered impact of 1.2 mm.

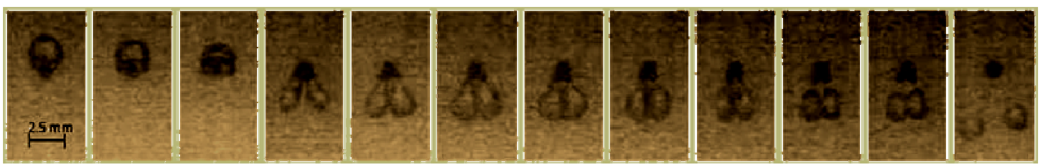

Figure 4: The centered impact of a 1.25mm diameter drop on a 0.79 mm diameter wire at an impact velocity of 0.60m/s.

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The critical eccentricity for each set of experiments has been extracted and presented in **Figure 5** vs. the impact velocity. The changes with velocity, wire thickness and drop size that have been mentioned can be seen in the figure, but overall the data points on the graph are scattered; in particular the results of a large drop radius that appear at high eccentricity values, which do not exist for smaller drops.

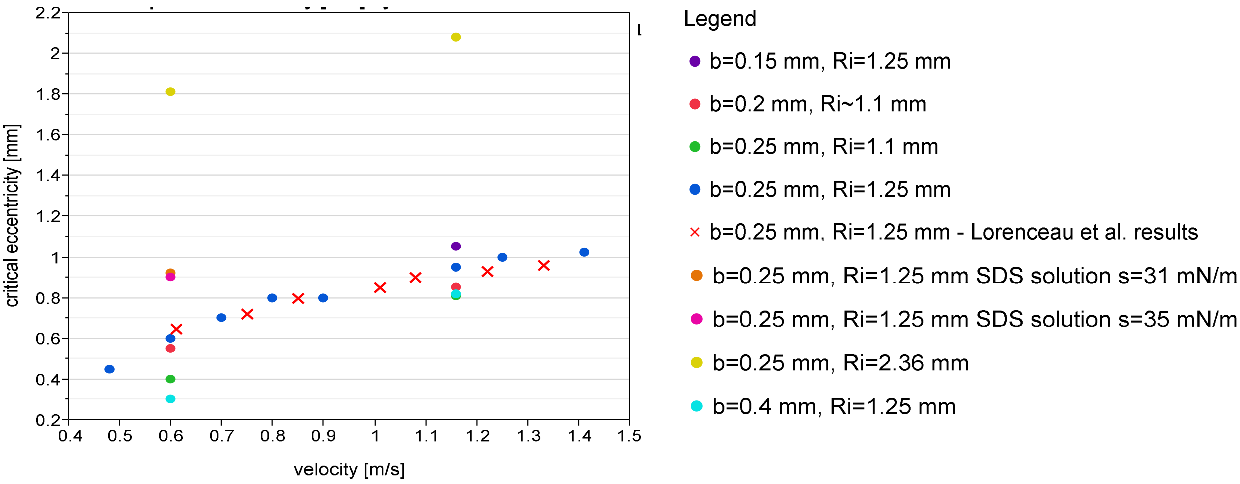

Figure 5: The critical eccentricity obtained from each experiment set vs. the impact velocity.

The criterion of capturing liquid by the wire

The suggestion, that there are two ranges of captured liquid, low and high, requires finding the critical eccentricity value where the transition from the uncaptured fragment to the captured fragment case is occurring and the amount of liquid that is captured by a wire is significantly increased. In order to estimate the criterion for the capture of liquid by a wire, we have developed a force balance that is acting on a drop with an **equivalent radius** throughout the impact-capture positions.

First we have defined the equivalent Radius, $\mathbf{R_{eq}}$, as the radius of a drop that is captured on a wire and its volume is equal to the captured fragment volume. The fragment volume is estimated as a cup with the initial drop radius and a height which is a subtraction of the eccentricity (the line where the wire slices the drop) from the initial drop radius, as described in **Figure 6**.

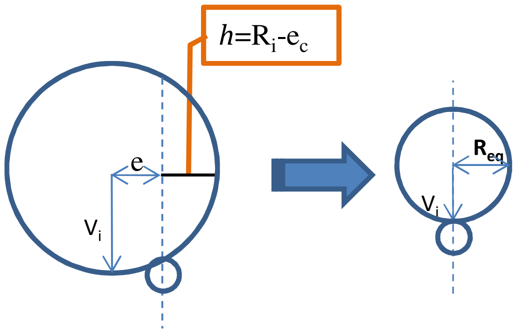

Figure 6: The equivalent radius, R_{eq}, which is extracted from the captured fragment volume that is assumed to be in a shape of a cup.

$$V_{eq.drop} = V_{cup}$$
$$\frac{4\pi}{3}R_{eq}^3 = \frac{\pi}{3}h^2 \cdot (3R_i - h)$$
$$R_{eq} = \left[\frac{1}{4}(R_i - e_c) \cdot (2R_i - R_i e_c - e_c^2)\right]^{1/3} \tag{4}$$

As mentioned, there are four forces that are acting on a drop falling on a body- capillary, drag, gravity and inertia. For a droplet to be captured by a wire, the total attachment forces, capillary and drag, should be larger than the sum of the detachment forces, gravity and inertia:

$$F_{capillary} + F_{drag} > F_{inertia} + F_{gravity} \tag{5}$$

The gravity term is simply:

$$F_{gravity} = \frac{4}{3}\pi R_{eq}^3 \rho g \tag{6}$$

The inertia term consists of the dynamic pressure and the equivalent drop projection area:

$$F_{inertia} = P_{dynamic} \cdot A_{projection} = \frac{1}{2}\rho v^2 \cdot \pi R_{eq}^2 \tag{7}$$

Regarding the attachment forces, the applied **viscosity** force is proportional to the shear stress and fluid-body surface area ($F_{drag}=\mu A \cdot dv/dy$). We use the images that were taken during the experiments to estimate an approximated surface area of the impact, see **Figure 3**c. Half the wire scope is multiplied by the drop diameter (which cannot be seen at **Figure 3** since the images present a front image).

$$A_{\text{impact}} = \pi \text{b} \cdot 2\text{R} \qquad (8)$$

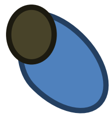

Figure 7: An approximation of the configuration of the captured fragment during the impact, according to Figure 3

The velocity gradient is measured between the impact velocity and the velocity near the body. As the velocity near the body equals zero, the estimated gradient is:

$$\Delta \text{v} = \frac{\text{v}_{\text{impact}}+0}{2} \qquad (9)$$

The film thickness (Δy) is approximately the same size as the droplet diameter, as can be estimated according to the sketch in **Figure 7**. Because of the problem geometry and the fact that the flow is not actually Newtonian fully developed, the viscosity forces involved are expected to be much bigger, so an effective viscosity of $\mu_{eff}=250\mu$ (cp) (which is much larger than the Newtonian fluid viscosity) was used to adjust the equation. This yields the following viscosity force:

$$\text{F}_{\text{drag}} = \frac{\pi}{2} \text{b} \cdot \mu_{eff} \text{v} \qquad (10)$$

The **capillary** force resulting from a horizontal wire is assumed to be equivalent to the force generated by two similar wires, connected to a drop at the same location of the actual wire-drop two symmetric contact points, but pointing radially, as described in **Figure 8**a.

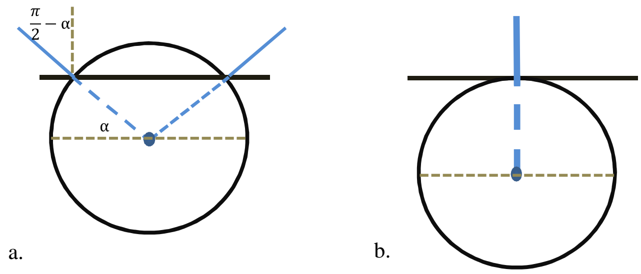

Figure 8: Configuration assumed to be equivalent to drop hanging on a wire; two wires (in blue) are connected to the drop at the same location of the actual wire-drop two symmetric contact points. b. the threshold position for crossing the wire, $\alpha=\pi/2$.

The threshold position for a drop before it crosses the wire is at $\alpha=\pi/2$ (see **Figure 8**b), therefore:

$$F_{capillary}=2 \cdot 2\pi b\sigma \qquad (11)$$

which is the maximum capillary force acting on a drop. This model has been introduced in Lorenceau et al. work [4] that described the capillary force acting on a static drop, hanging on a horizontal wire, and defined the critical size of the hanging drop. Their results have shown indeed a linear relation between sin α and the dimensionless quantity R^3/bk^{-2}, which represents the two forces acting on a pending drop - gravity and surface tension.

The complete criterion for capturing liquid by a wire, after combining all terms is presented in equation (12):

$$4\pi b\sigma + \frac{\pi}{2} \text{b}\mu_{eff}\text{v} > \frac{\pi}{2}\rho \text{R}_{eq}^2 \text{v}^2 + \frac{4}{3}\pi {\text{R}_{eq}}^3 \rho g \qquad (12)$$

By dividing this equation by the inertia term, we get the non-dimensional equation for an equivalent drop to be captured on a horizontal wire. The equation consists of four non-dimensional groups;

$\text{Re} = {\rho \text{v} \text{R}_{eq}}/{\mu_{eff}}$, $\text{We} = {\rho \text{v}^2 \text{R}_{eq}}/{\sigma}$, $\text{Fr} = {\text{v}}/{\sqrt{g\text{R}_{eq}}}$ and the wire-drop radii ratio- ${\text{b}}/{\text{R}_{eq}}$:

$$8\left(\frac{b}{R_{eq}}\right)\frac{1}{We}+\left(\frac{b}{R_{eq}}\right)\frac{1}{Re}-\frac{8}{3}\frac{1}{Fr^2}>1 \qquad (13)$$

By substituting zero for velocity, we set the maximum size of a static droplet, hanging on a horizontal wire.

$$R<\left(\frac{3b\sigma}{\rho g}\right)^{1/3} \qquad (14)$$

Any drop larger than this would detach the wire. The same result for a threshold drop size for a drop hanging on a fiber has been found in Lorenceau et al. [4] analysis.

Since this is a cryptic equation, the critical eccentricity has been solved by trial and error calculations. For a given drop size, a wire diameter and liquid surface tension, a critical eccentricity was guessed to give an equivalent drop radius (from equation (4)) that would yield the desired velocity (from equation (13)), which is the impact velocity in the experiments. The calculated results of the critical eccentricity, compared with the experimental results are presented (as ratio) in **Figure 9** as a function of square Froude number, and also in **Figure 10** as an overlay plot of calculated and experimental results versus Weber number. As can be seen, the calculated results are in very good agreement with the experimental results along the range of 3-13 Froude and 3-45 Weber numbers. All the points in **Figure 9** are concentrated around the value of 1 (including the two deviated points of large drop radius from **Figure 5**) with only 10% error for most of them. Therefore, it seems that equation (13) (along with equation (4)) successfully captures the experimental observation, and following these findings, we conclude that the equation provides a reliable criterion for capturing liquid by a wire.

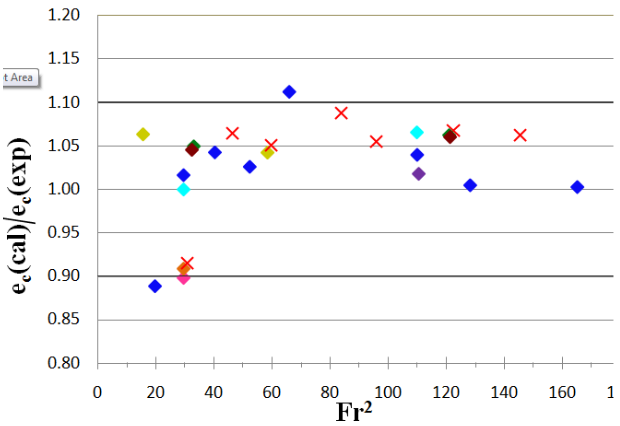

Figure 9: Calculated/experimental eccentricity ratio vs. Froude No.^{2} for various parameters.

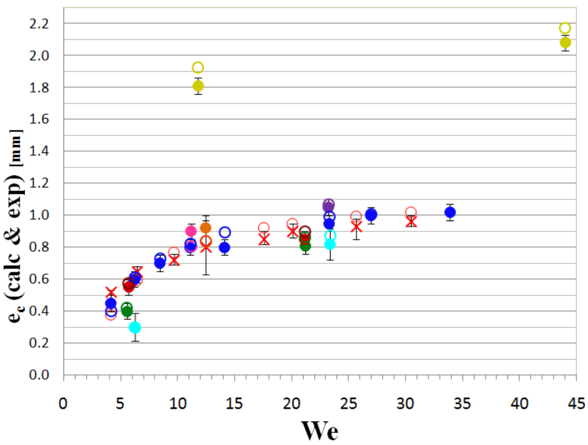

Figure 10: Calculated (cavitary mark) and experimental (filled mark) eccentricity vs. Weber No. for various parameters.

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References

[1] Schemenauer, R. S. and Cereceda, P., *J. Applied Meteorology* 33:1313-1322 (1994).
[2] Contal, P., Simao, J., Thomas, D., Frising, T., Callé S., Appert-Collin, J.C. and Bémer, D., *Aerosol Science*, 35:263 (2004).
[3] Lorenceau, E., Senden T., and Quéré D., *Molecular Gels part 2*, R. G. Weiss, P. Terech, 2006, p. 223-237.
[4] Lorenceau E., Clanet C., and Quéré D., *Journal of Colloid and Interface* Science 279: 192–197 (2004).
[5] Boucher, E.A. and Evans, J.B., *Proc. R. Soc. London*, A346:349 (1975).
[6] Padday, J.F. and Pitt, A.R. *Phil. Trans. R. Soc. Lond.A*, 275:489-528 (1973).
[7] Tate, T., *Philosophical Magazine*, 27:176 (1864).
[8] Hung, L.S., Yao, S.C., *International Journal of Multiphase Flow* 25: 1545-1559 (1999)
[9] Pasandideh-Fard, M., Bussmann, M., Chandra, S., Mostaghimi, J., *Atomization and Sprays* 11:397-414 (2001).
[10] Lorenceau E., Clanet C.,Quéré D., and Vignes-Adler M., *The European Physical Journal Special Topics*, 166: 3-6 (2009).
[11] Zar, J.H., *Biostatistical Analysis*, [4th ed.] ,99 & 208-222 (1999).
[12] Quéré, D., AccessScience- McGraw-Hill (2008), (http://www.accessscience.com)