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EFFICIENCY OF *ALOE ARBORESCENS* AND *ALOE BARBADENSIS* SPECIES AS DRAG REDUCERS

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Abstract. *Studies have proved that the mucilage of Aloe vera is a good polymeric additive to be used as drag reducer in turbulent flows, besides being natural and easy to obtain. However, there are many varieties of the plant. This work evaluates two different species of the plant, Aloe arborescens and Aloe barbadensis, in order to verify if there is any difference in their capacity to reduce the friction factor in the transport of fluids. In order to achieve this objective, it was necessary to plant and cultivate the plants in similar conditions and a specific methodology for extraction of the concentrated mucilage was followed. The rheological characterization was done using a rheometer, in which the drag reduction tests were also performed. The results show that the species Aloe arborescens has higher efficiency in reducing the flow resistance than Aloe barbadensis.*

Keywords: *turbulence, drag reduction, biopolymer, Aloe barbadensis, Aloe arborescens.*

1. INTRODUCTION

Since the discovery of Toms (1948) that high molecular weight polymers can reduce the drag in turbulent flows, this subject has been widely investigated for the use in industrial, environmental and medical applications. One of the most well known examples is the case of the *Trans-Alaska* pipeline (Burger and Chorn, 1980).

The use of *Aloe vera* as a drag reducing agent (DRA) was reported by Abdulbari, Letchmanan and Yunus (2011), who found that this polymer can reduce up to 63% of friction in a turbulent flow and, more recently, Barbosa (2017) demonstrated the potential of *Aloe vera* compared to Xanthan Gum and Polyethylene Oxide (PEO), stressing its advantage for being natural, non-toxic, relatively cheap and easy to obtain.

There are many species of *Aloe vera* and, according to Grace (2011), the properties of leaves and chemical composition of mucilage can change among the species. As reported by Cardarelli *et al.* (2013), the species *Aloe arborescens* and *Aloe barbadensis* are the most cultivated. So, this work proposes to compare the mucilage of this two species to determine the one that presents the best drag reduction capacity.

2. METHODOLOGY

Four samples of each species of *Aloe vera* were planted. The seedlings were positioned in two rows, 1.30 meters apart with 0.60 meter spacing between plants, as prescribed by Bach and Lopes (2007). The plants were harvested after a period of two months and the leaves selected according to length, width and thickness, to characterize the plant age, as indicated by literature (Paleari and Dos Santos, 1998; Monteiro *et al*., 2005; Lima *et al*., 2011). Table 1 shows the values used as base to characterize the plants dimensions during the harvest.

Table 1. Values used for comparison of *Aloe* species.

Length (cm)	Maximum thickness (cm)	Maximum width (cm)
25.6	1,1	2,9

2.1 Polymer extraction and storage

The mucilage of *Aloe* was obtained following the methodology proposed by Barbosa (2017), as represented in Fig. 1. The leaves were washed and dried. The outer leaves were removed and the inner leaves, which are composed of mucilage and fibers, were used to obtain the concentrated mucilage. In order to separate the mucilage from fibers the inner leaves passed through a grinder and three filtration processes. The first filter consisted of 100% polyester tulle; the second and third filters were a 1.80 mm and a 106 micrometers sieve, respectively. Finally, the solution obtained was homogenized and packed in recipients, according with the amount used in each test, and the recipients were taken immediately to a freezer to prevent degradation of the material.

a) *Aloe* leaves b) inner leaves c) grinding process

d) Tulle filtration e) 1.8 mm filter f) 160 μm filter g) concentrated mucilage

Figure 1. Steps of the *Aloe vera* mucilage extraction.

2.2 Rheological characterization and drag reduction tests

Aloe arborescens is not a common plant in the northern region of Espírito Santo, although it is common elsewhere. Thus, because there were not many seedlings available until the time of the tests, it was not possible to obtain a large amount of mucilage. Since the quantity obtained by the processing step was small, the drag reduction tests were done in a rheometer, consisting of double gap concentric cylinders (HaakeMars II), the same used by Pereira and Soares (2012), Pereira, Andrade and Soares (2013), Coelho *et al*. (2016) and Barbosa (2017) and as illustrated in Figure 2.

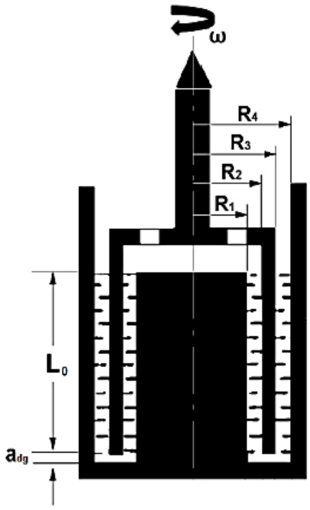


Figure 2. Double gap geometry.
Source: Barbosa (2017).

To calculate drag reduction is necessary find the friction factor with the geometry used. The friction factor of the solution can be calculated as indicated by Eq. (1).

$$f = \frac{2\tau}{\rho u^2} = \frac{2\tau}{\rho(\omega\bar{R})^2} \quad (1)$$

On Eq. (1), $\omega\bar{R}$ is a characteristic velocity, $\bar{R}$ is the mean radius ($\bar{R} = (R_2 + R_3)/2$), τ is the nominal shear stress and ρ the density of the solution. With this parameter calculated, it is possible define the drag reduction as a function of the friction factor of solution (f_p) and friction factor of solvent (f_0), (Eq. 2).

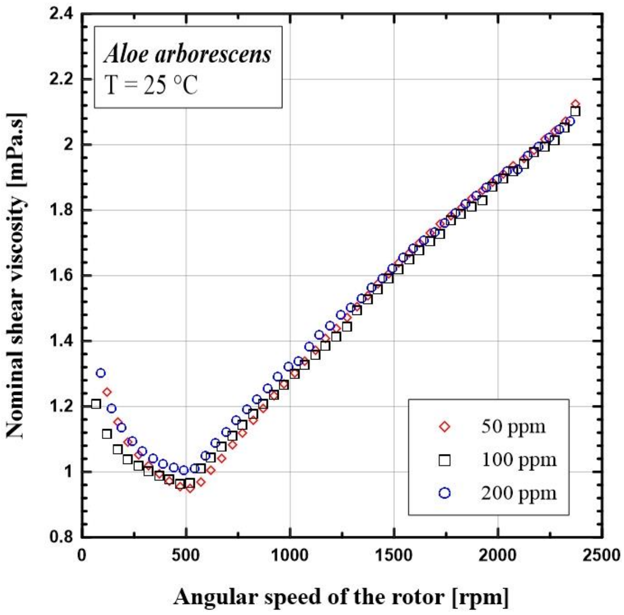
$$DR = 1 - \frac{f_p}{f_0} \quad (2)$$

The tests to determine the viscosity of the solutions were done at concentrations of 50, 100 and 200 ppm, with a constant temperature of 25 °C. The viscosity was established with the variation of the rotor angular velocity from 0 to 2400 rpm, range that the flow is still classified as laminar, during a period of 480 seconds, since, from that moment on, the first instabilities occur and the flow presents a turbulent regime.

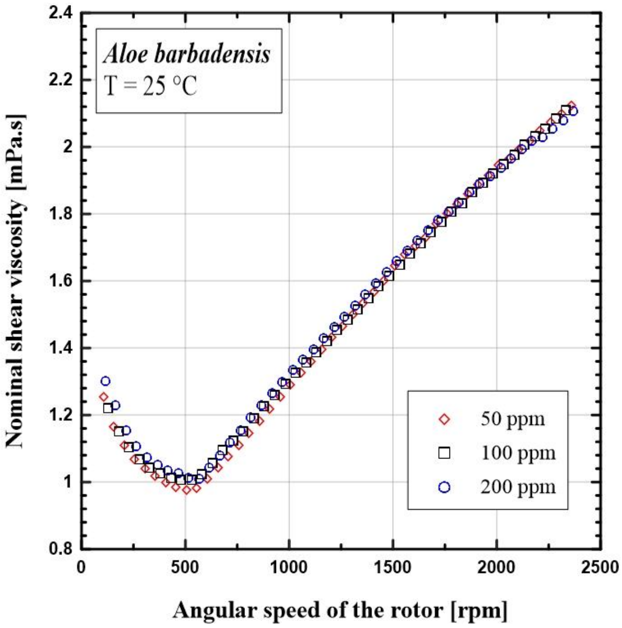
The second type of test performed on the rheometer was to determine the drag reduction over time for each species. In this case, during a 2000 seconds interval, the rotor rotation was kept fixed at a Reynolds number of 1360.

3. RESULTS AND DISCUSSION

The tests conducted to determine viscosity of each species of *Aloe* are shown in Fig. 3. For both species, the viscosity values were practically the same for the three concentration values. At the beginning of the curve, there was a decrease in viscosity, a region where the flow is characterized as laminar. Thereafter, there was an increase in viscosity and the flow is characterized as turbulent. For the calculation of the Reynolds number in the experiments, the minimum point of each curve was used.



a) *Aloe arborescens*



b) *Aloe barbadensis*

Figure 3. Flow curves for the two species of *Aloe*.

The tests of drag reduction as a function of time that compare the two species studied were performed for three different concentrations, and the results are shown in Fig. 4. For *Aloe arborescens*, the curve decayed after the maximum value was reached, probably due to some desagregation that happened with the polymer. At approximately 100 seconds, it was observed that the curves tend to a constant value. Analyzing the asymptotic part of both species, at the time of 200 seconds, there were differences of approximately 1,9% in drag reduction for the concentration of 50 ppm and 0,9% for the concentration of 100 ppm. For the concentration of 200 ppm, the values of the difference were 0,5%. Concerning the maximum drag reduction, the values were also higher for *Aloe arborescens* than *Aloe barbadensis*, being the difference equal to 5% for 50 ppm, 1,2% for 100 ppm and 3,8% for 200 ppm. So, it seems that *Aloe arborescens* is more efficient in reducing drag than *Aloe barbadensis*, observing the maximum drag reduction and the asymptotic regime values. Yet, according to Fig. 4, at the beginning of the curve, the development time is observed, which is the time necessary to develop the turbulent structures and is characterized by the increase in DR. After the development time, the resistance time occurs, where the value reached is kept constant. This asymptotic behavior happens only for *Aloe barbadensis*. The study shows that each species can lead to a difference result concerning their capability to reduce drag and, for the same concentration of polymers, *Aloe arborescens* presented higher DR efficiency when compared to *Aloe barbadensis*.

With the drag reduction tests performed, the chemical characterizations is necessary to verify if the chemical composition is different between species, which may explain the efficiency of the species being different.

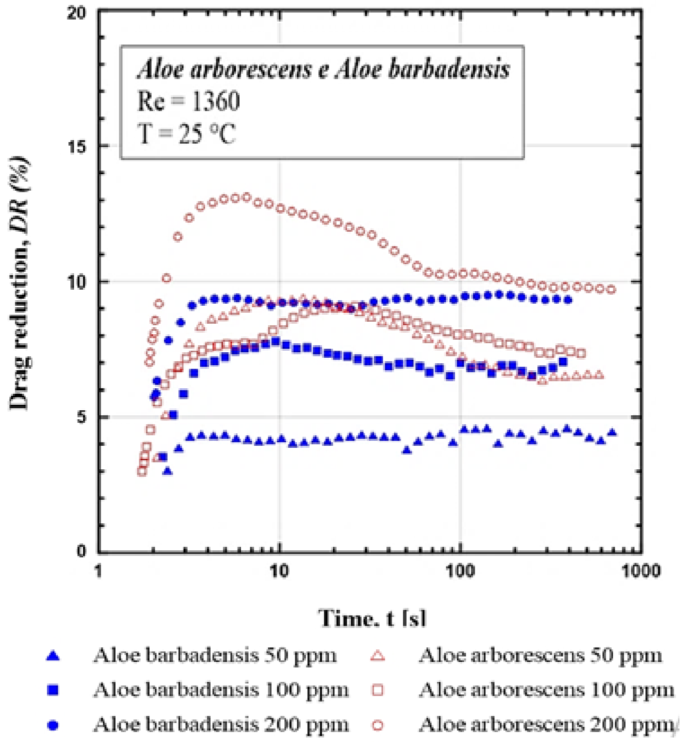


Figure 4. Comparison of the species *Aloe barbadensis* and *Aloe arborescens* relative to effect drag reduction and concentration.

4. ACKNOWLEDGMENTS

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