Particle Size Analysis and Roundness Distribution For more economical BSFI

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Abstract

Reduction of particle sizes in biomass slurries has long been established to be a major factor in reducing the slurry viscosity. The additional factor is the particle shape and roundness as it effects the particle-particle interactions increasing the shear rate and thus increasing the viscosity of the entire slurry. The importance of reducing the viscosity of slurries lies in the increase in economic feasibility of biomass related projects. This project aims to identify if Lignosulfonic Sodium Salt Acid increases the roundness of the particles in hydrochar slurry solutions. The study utilizes python code to produce histograms and statistics to compare different treatments of Lignosulfonic Acid on the slurries and how it affects their roundness coefficients. Despite the initial hypothesis that the addition of Lignosulfonic Sodium Salt Acid to the slurries will significantly increase the roundness of the particles, the results dictate that there is no existing correlation between the two. The likely reasoning lies in there being no visible changes to the particles and instead the alteration of the particles is molecular.

Introduction

The importance of reducing viscosity in biomass slurries lies entirely in the economic feasibility of biomass related projects. In this particular case, we intend to reduce the viscosity of biomass slurries for more efficient sub-surface fracture injection as a means for carbon capture in order to turn a profit and negate the costly requirements for transportation and pretreatment. In many applications such as the biofuels industry, higher viscosities can significantly impair the efficiency of its conversion into a usable fuel source. Many of these complications arise in the pumping and spraying aspects of the industry(Kuznetsov et al., 2021). One of the components that significantly reduces viscosity is reduction of particle size and analysis of roundness and spherical characteristics. Such examples have been cited in works relating to enzymatic hydrolysis of biomass slurries where it was determined that reducing particle size directly corresponded to lower viscosities(Dasari & Berson, 2007). The significance of such reductions has significant economic implications throughout multiple industries via increased solid loading and lower energy requirements in transport and conversion. This project analyzed the treatment of pine chip slurries with hydrothermal carbonization and the addition of Lignosulfonic Sodium Salt Acid and their resulting Wadell's Roundness Coefficients to determine the best treatment method for more spherical particle sizes. The hypothesis going into this project was that each addition of Lignosulfonic Sodium Salt Acid will significantly increase the roundness of the pine chip particles.

Methods

The initial process began with retrieving pine chips from Tractor Supply Co. Next the pine chips were milled using a disc grinding mill and sieved through a 300 micron sieve so that the resulting particles were less than or equal to 300 microns. The particles were then weighed out so that exactly 15g of pine chip particles were used. These particles were then mixed with 150mL of tap water and mixed with a laboratory spatula until they were seemingly fully mixed with the water. This process was repeated two more times to obtain a total of three slurries that would receive three different treatments: control treatment with 0g of Lignosulfonic Sodium Salt Acid (LSA) added, 2.5g LSA added, and 5g LSA added. The slurries were then mixed again until the LSA was completely dissolved in the slurry. The slurry was then transferred into a high temperature pressurized reactor where it was heated to 250°C for 1 hour and let rest over two days at room temperature until removal from the reactor. The solids and liquid were then separated and the resulting solids were then dried at 60°C for two days. This process was repeated for all three slurries. Next each treatment was removed from the drying oven and a 0.5g sample was taken and analyzed under a microscope. A total of 40 particles were measured using the measurement technique as illustrated in *Figure 1*.

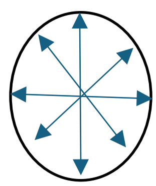

Figure 1. Measurement technique of the particles

The four measurements were then recorded from smallest to largest and Wadell's roundness coefficient with the formula $R = (\frac{1}{n}\sum_{i=1}^{n} r_i)/r_{max}$ (Cruz-Matías et al., 2019). "Where n is the number of corners, r_i the radius of the ith corner curvature, and r_{max} the radius of the maximum inscribed circle. R is 1 for a perfectly round object and less than 1 for any other object" (Cruz-Matías et al., 2019). Using python's matplotlib, numpy, and pandas packages, the roundness coefficients were plotted as histograms (*Figures 2-4*) and the means were determined. A scatterplot displaying 1 – the mean of each treatment's roundness coefficient was created to display the relationship between treatment and roundness coefficient (*Figure 6*).

Results

The first thing that became obvious after analysis was that there was no clear relationship between the addition of LSA and the roundness of the particles. The mean roundness coefficients were as follows: 0g LSA treatment 0.7676983536410256, 2.5g LSA treatment 0.7521571579999999, and 5g LSA treatment 0.761445730275. The histograms also displayed very similar shapes and distributions of the roundness coefficients. The final clue as to there being no significant effect on the roundness of the particles by the addition of LSA was the one minus mean calculations that were all within ± 0.02 of each other, 0g treatment = 0.23230164635897443, 2.5g treatment = 0.24784284200000006, and 5g treatment = 0.23855426972500005. Despite the literature stating that the addition of lignosulfonates reduces the interactional tension within drilling fluids (Browning, 1955), the results clearly dictate that there is no clear observable change between treatments. The analysis did however determine that within the samples the control treatment exhibited the roundest particles followed by the 5g treatment. Lastly a particle size distribution histogram was created for the columns in each treatment's dataset that contain the largest particle size measurements (*Figure 7*). The results of this histogram displayed similar distributions amongst all three treatments with very few outliers. Due to these results, we must reject our initial hypothesis. These results, based on the literature, also indicate that there is no reduction in the particle-particle interactions within the slurry from the addition of Lignosulfonic Sodium Salt Acid.

Discussion

These results were initially off-putting. The literature stated that the addition of lignosulfonates affects the steric/electrostatic repulsive interactions between the particles (Konduri & Fatehi, 2019) which in hand would reduce the viscosity of the slurries. While this does not state that there would be an effect on the particle size or shape one could infer that the alteration of these interactions might be due to a decrease in the particle-particle interactions. The results of this study, however, displayed that there is no detectable alteration to particle size or shape from the addition of LSA. Upon further investigation this may be due to the fact that the addition of LSA affects the particles on a molecular scale undetectable to the human eye even with the assistance of a microscope. Another explanation could be that the sample size was not large enough and therefore was a poor representation of the entire population. The greatest source of error could also be related to the usage of human measurements. There could have been some bias in selection of particles to measure, selecting only those that were easy to measure by hand. In the future using a 3d particle size analyzer may produce more accurate results that may indicate that there does exist a relationship between particle shape and size with the addition of LSA. What is clear after this study is that further analysis must be done to determine the effect of LSA on biomass slurries. In understanding how LSA can lower viscosity of slurries, carbon capture and biofuel projects can become more economical with a higher return on investment. With the inexpensive nature of LSA and the ease at which it can be produced it would be a significant finding if one can determine the exact nature of LSA's relationship with biomass slurry viscosity. Such findings could significantly contribute to the success of the ongoing energy transition and may further delay the impending climate crisis. What is clear after this study is that there is a need for further and more refined analysis of what Lignosulfonic Sodium Salt Acid can do to biomass slurries. There is also a rising need to discover a method to alter the shape of the particles to decrease the particle-particle interactions so that the viscosity of the slurries can decrease therefore increasing economic feasibility of these projects. Determination of a solution to the physical interactions that cause an increase in viscosity could greatly service a variety of industries and could prove to one day be a multi-million dollar solution with the carbon credit incentives factored in. This study however came up with inconclusive data to determine such a solution but that is not to say that there are no solutions out there.

Figures

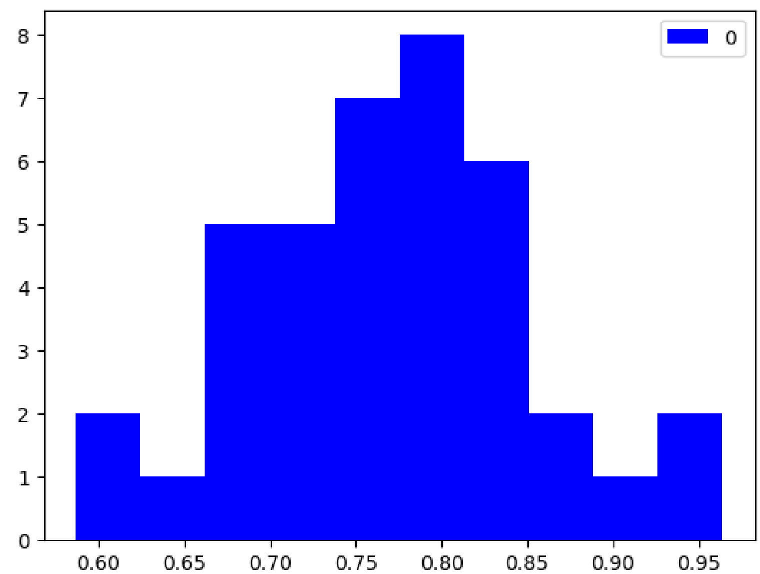

Figure 2. Histogram of Wadell's Roundness Coefficient for the 0g LSA Treatment

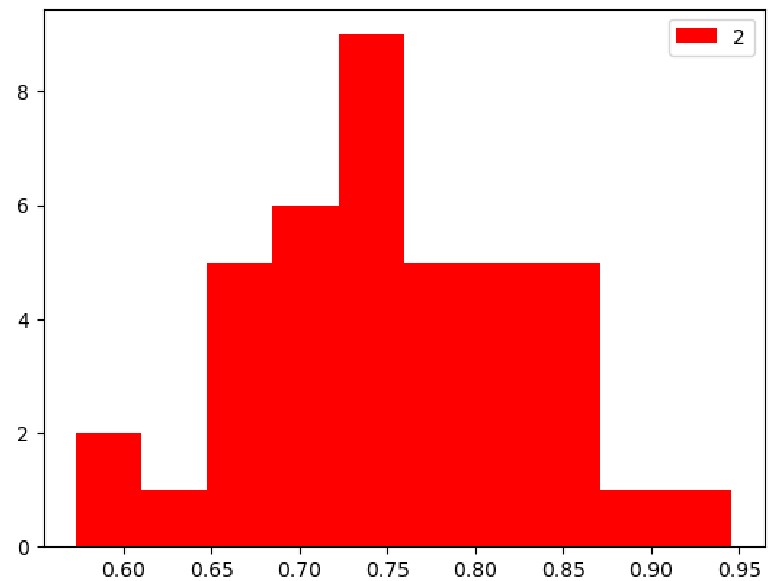

Figure 3. Histogram of Wadell's Roundness Coefficient for the 2.5g LSA Treatment

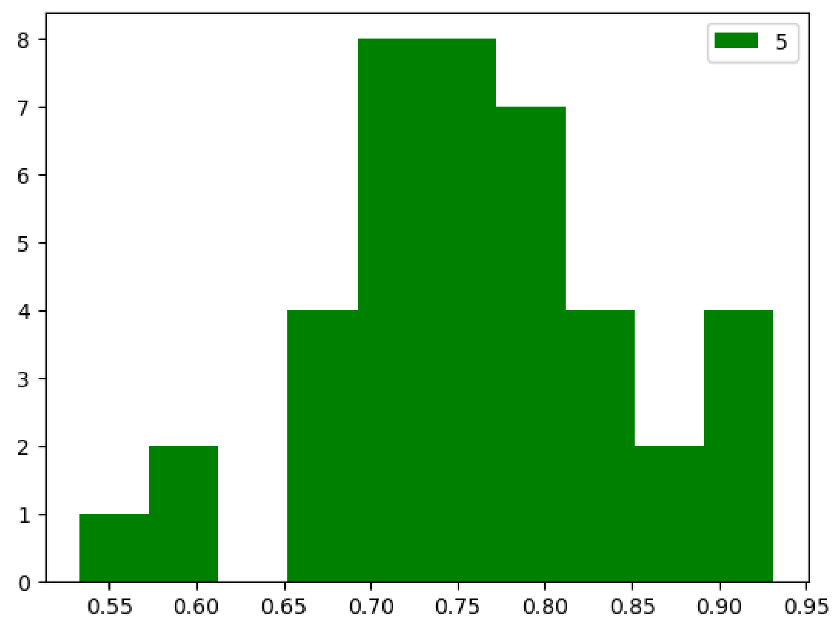

Figure 4. Histogram of Wadell's Roundness Coefficient for the 5g LSA Treatment

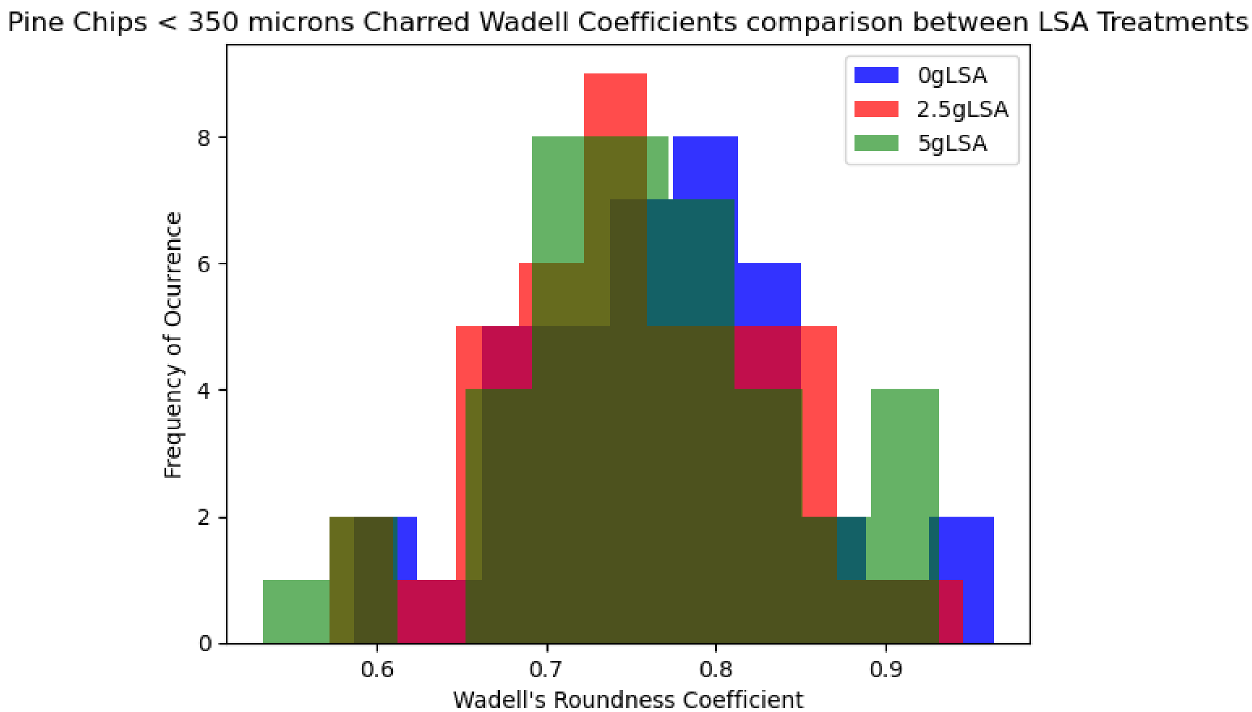

Figure 5. Histogram of Wadell's Roundness Coefficient for All Treatments

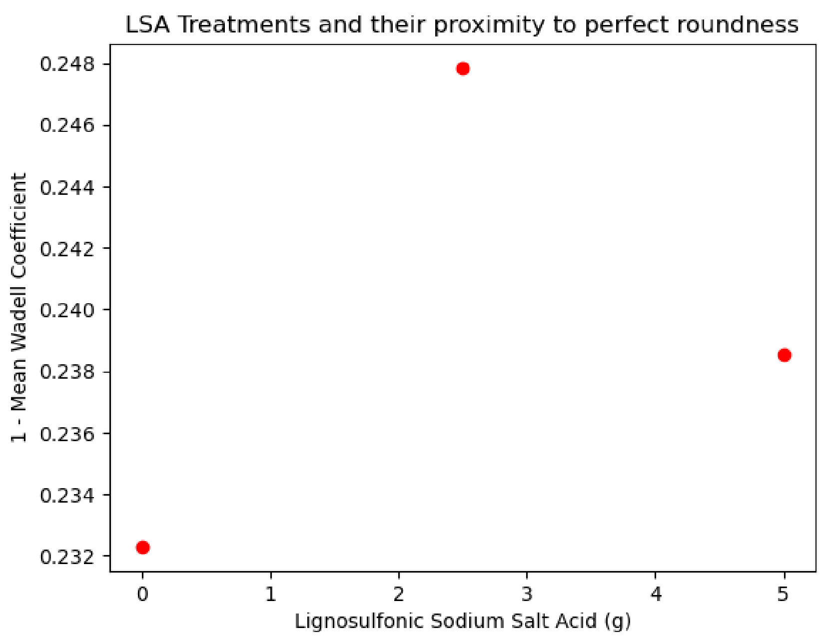

Figure 6. One minus Mean Wadell's Roundness Coefficient versus amount of Lignosulfonic Sodium Salt Acid added.

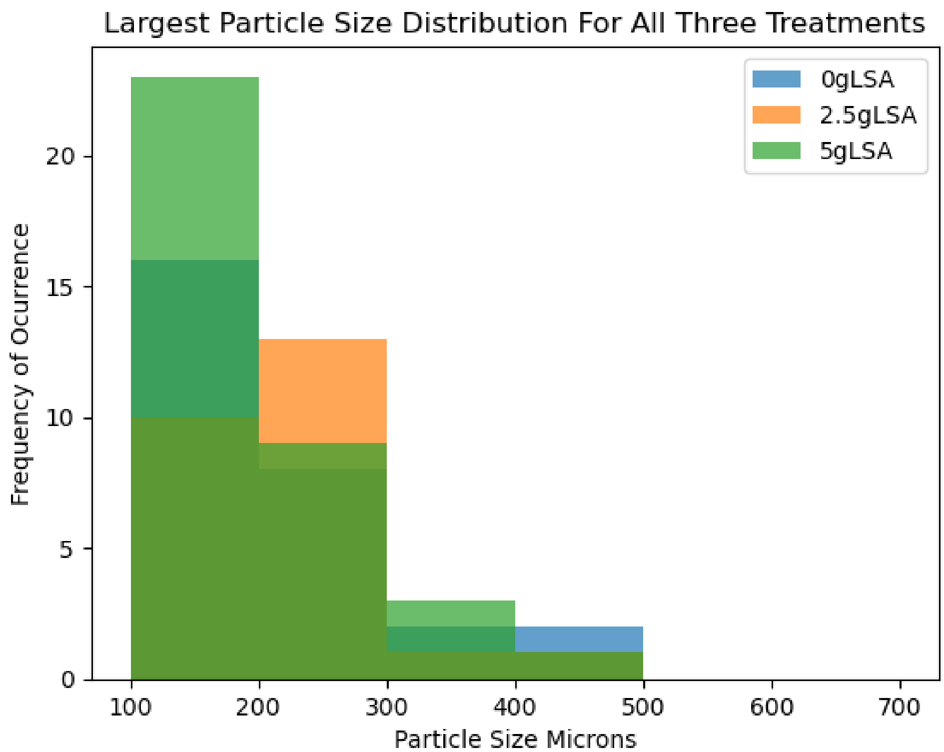

Figure 7. Particle Size Distribution of the largest particle size column for each Treatment

References

Browning, W. C. (1955). Lignosulfonate Stabilized Emulsions in Oil Well Drilling Fluids. *Journal of Petroleum Technology*, *7*(06), 9–15. https://doi.org/10.2118/393-G

Cruz-Matías, I., Ayala, D., Hiller, D., Gutsch, S., Zacharias, M., Estradé, S., & Peiró, F. (2019). Sphericity and roundness computation for particles using the extreme vertices model. *Journal of Computational Science*, *30*, 28–40. https://doi.org/10.1016/j.jocs.2018.11.005

Dasari, R. K., & Berson, R. E. (2007). The Effect of Particle Size on Hydrolysis Reaction Rates and Rheological Properties in Cellulosic Slurries. In J. R. Mielenz, K. T. Klasson, W. S. Adney, & J. D. McMillan (Eds.), *Applied Biochemistry and Biotecnology: The Twenty-Eighth Symposium Proceedings of the Twenty-Eight*

Symposium on Biotechnology for Fuels and Chemicals Held April 30–May 3, 2006, in Nashville, Tennessee (pp. 289–299). Humana Press. https://doi.org/10.1007/978-1-60327-181-3_26

Konduri, M. K. R., & Fatehi, P. (2019). Alteration in interfacial properties and stability of coal water slurry by lignosulfonate. *Powder Technology*, *356*, 920–929. https://doi.org/10.1016/j.powtec.2019.09.019

Kuznetsov, G. V., Romanov, D. S., Vershinina, K. Yu., & Strizhak, P. A. (2021). Rheological characteristics and stability of fuel slurries based on coal processing waste, biomass and used oil. *Fuel*, *302*, 121203. https://doi.org/10.1016/j.fuel.2021.121203

Appendix

Code :
https://github.com/chsharrison/Sci_comp_F24/blob/main/Zachary_Laird/Working%20Notebook.ipynb