Analysis of Separation Efficiency of an Advanced Annular Couette Centrifuge in Open-Loop Mode

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GOALS

- Determine if centrifugation in an open-loop setup improves when replacing solid body rotation with differential rotation, specifically for sub-micron sized particles.
- Collect concentration measurements ex-situ to test the separation efficiency of the device over time.

MOTIVATION

- This experiment mimics a steady operation mode. It is more closely related to how centrifuges function in industry, as opposed to batch mode.
- An increase in separation rate of existing centrifuges may increase time and cost efficiency.
- Separation of sub-micron sized particles may improve existing application areas and/or open-up new ones.

BACKGROUND

Advanced Annular Couette Centrifuge (AACC)

- Modified Taylor-Couette device consisting of differentially rotating lids, an inner and outer cylinder, an inner ring, a pump connected to several configurable inlets and outlets, and 2mm annular slots for symmetric in flows and out flows. It holds up to 15 gallons of water.
- A fast-rotating inner cylinder is expected to increase local effective gravity.
- The inner ring prevents secondary flows, which would re-mix separated phases and undermine the usefulness of a quickly rotating inner cylinder.
- Outlets lead to two buckets: one which holds deposited water, and one which acts as a reservoir.
- LabView software controls rotation of the inner ring and outer cylinder.

Centrifuge Experiments

- Titanium Dioxide, TiO_2 , is available as a sub-micron sized (200-nm) powder. It has a brilliant white color, is insoluble in and 4x the density of water. Its properties make it an interesting candidate for centrifuge testing.
- AACC spins with both cylinders moving in the forwards direction. The spinning pushes the powder to the walls of the outer cylinder due to centrifugal force.
- Previous experiments have been conducted in batch mode. Current runs now incorporate the pump driving an inlet while two outlets either recirculate or reject material.
- Both solid body and differential rotation conditions are tested for separation efficiency:

  Solid Body Rotation: 100 rpm used for measurements.

  Differential Rotation: 754 rpm, 185 rpm, 100 rpm used for measurements.

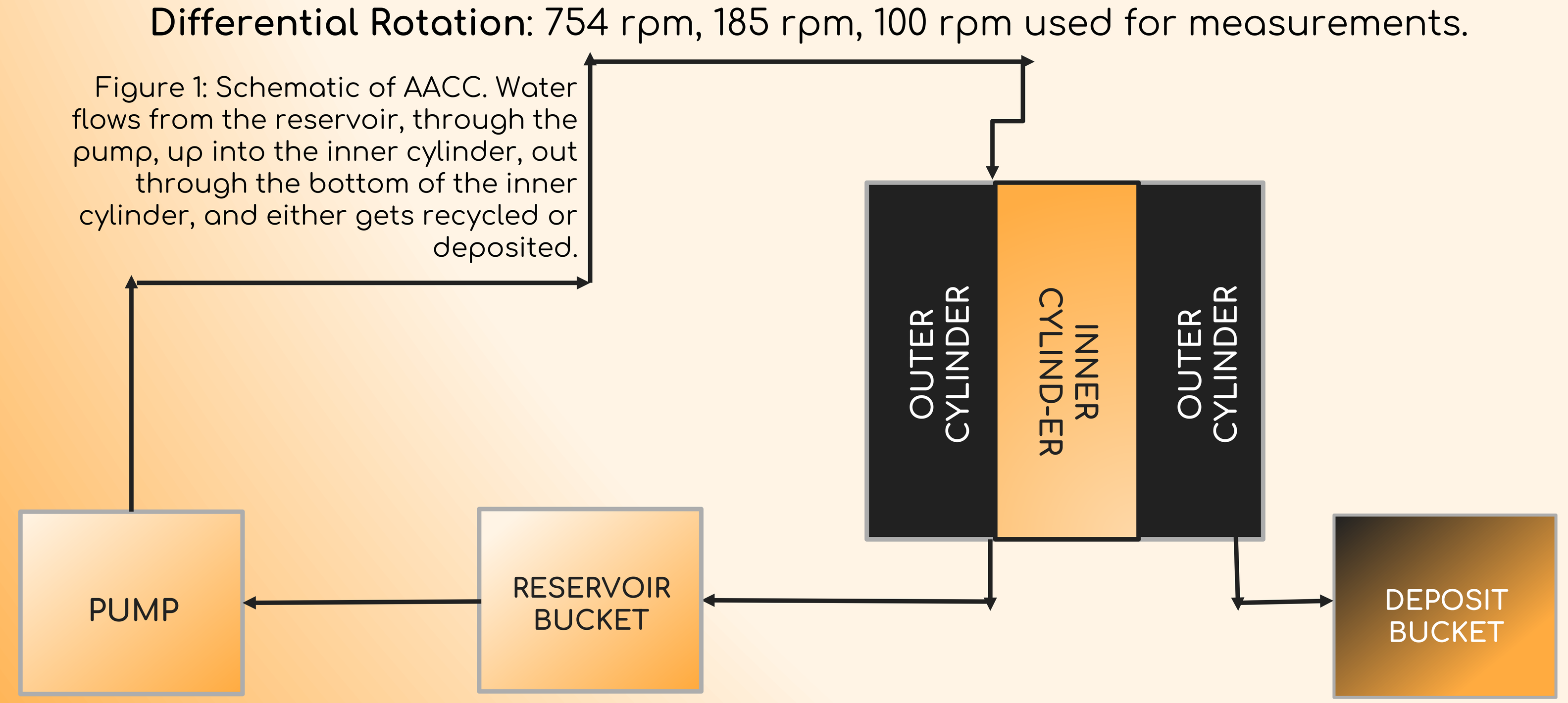

Figure 1: Schematic of AACC. Water flows from the reservoir, through the pump, up into the inner cylinder, out through the bottom of the inner cylinder, and either gets recycled or deposited.

EXPERIMENTAL SET-UP

- The powder is inserted into AACC via the recycling bucket.
- Water initially flows from the reservoir, into the pump and through the apparatus from above until uniform.
- An increase in centrifugal force within the cylinder pushes water + TiO_2 out of the device through a series of tubes. Some of it is recycled back into the system, while the rest is later removed to the deposit bucket.
- Run time is about 15 minutes with a 2:1 flowrate ratio between buckets:

  Recycle flowrate: 0.36 gpm

  Deposit flowrate: 0.16 gpm
- Samples are collected from the recycling bucket stream every 60 seconds.


Figure 2 AACC. The black cylinder represents the inner cylinder while the clear cylinder is the outer cylinder. The network of inlets and outlets can be seen by the series of blue and clear plastic tubes lining the sides and top of the apparatus. The deposit and recycling bucket (not shown) are to either side.

MEASUREMENT METHODS

Two methods were considered, laser absorption spectroscopy and laser refractometry method to determine the concentration of samples. A Z-bolt 8-mm green laser diode (Class 3R, 532-nm) was shined through a glass container holding water and TiO_2 particle samples.

Laser Absorption Spectroscopy (LAS) Method

- Images of the laser passing through samples was captured by a Princeton Instruments camera.
- WinSpec software helped determine the intensity of the pixels once the laser exited the material.
- Increasing total intensity would imply the particles are being centrifuged out of the system.
- Shots are run through Python script to map externally and determine total intensity over time.

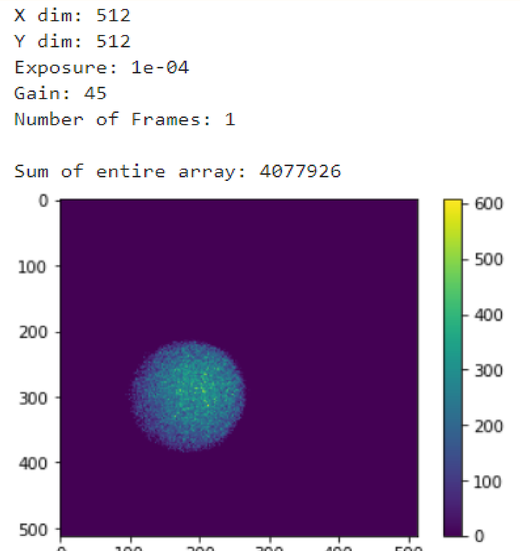

Figure 3: Image of laser as shown on Python. The exposure of the camera could be adjusted to better capture the pixels and their associated brightness.

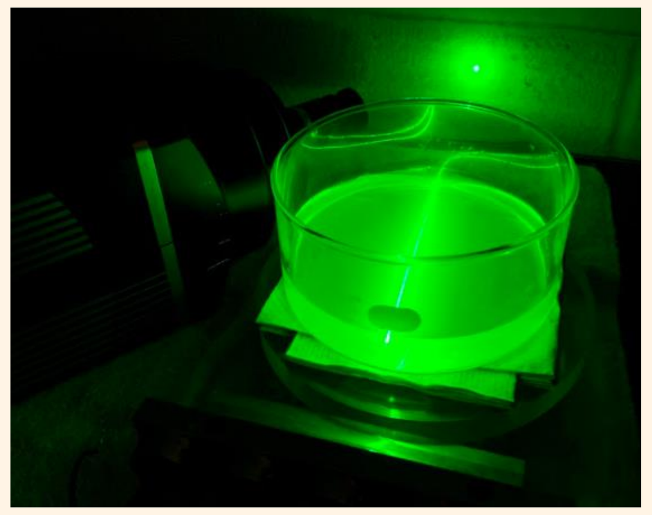
Figure 4: LAS setup. The laser is shot through the center of the glass container, with the PI camera capturing the image on WinSpec software.

Laser Refractometry Method

- TiO_2 has a high refractive index (Rutile phase: n=2.614), motivating this method.
- The laser was shot into the sample at an angle to determine concentration based on refraction of the laser.
- Method abandoned upon difficulty in observing refraction through medium(s).

RESULTS

Collected data suggests differential rotation is more effective for centrifugation of sub-micron sized particles than solid body rotation, even in an open-loop system.

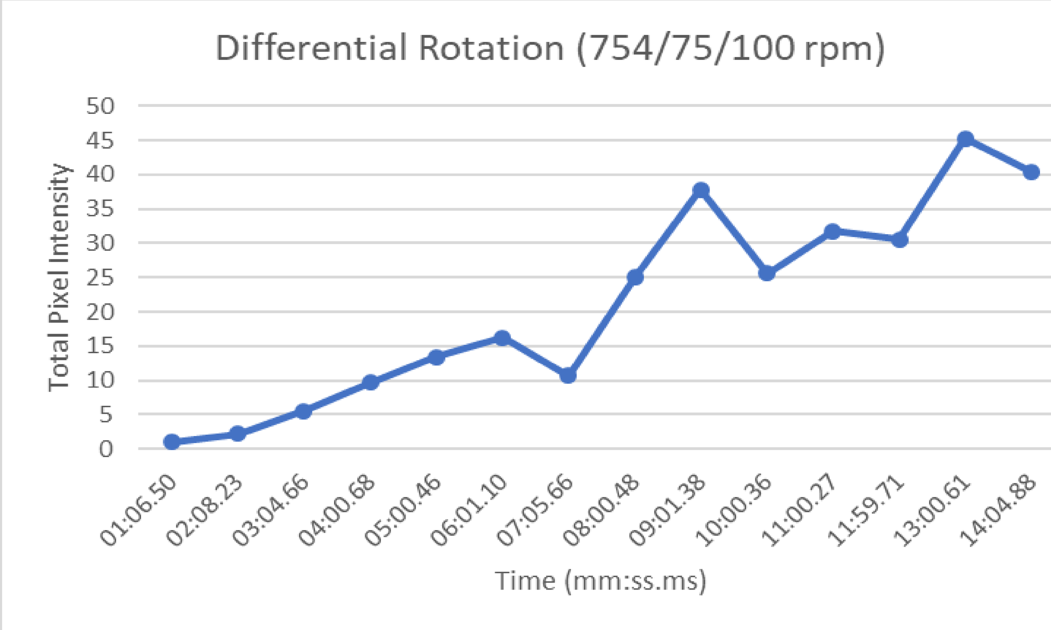

Figure 5: A plot of AACC's intensity over time during differential rotation. Fourteen samples were taken every 60-seconds, for about 14 minutes.

The upwards trend of intensity over time is taken as an indication of particles being centrifuged out. As water from the recycling bucket became clearer over time, a higher overall pixel intensity was expected. This also shows that the setup is successful in recycling cleaner water.

An insignificant increase in intensity for solid body rotation supports the apparatus is not efficient for solid body rotation. This graph indicates the water collected from the recycling bucket did not greatly decrease in concentration of particles.

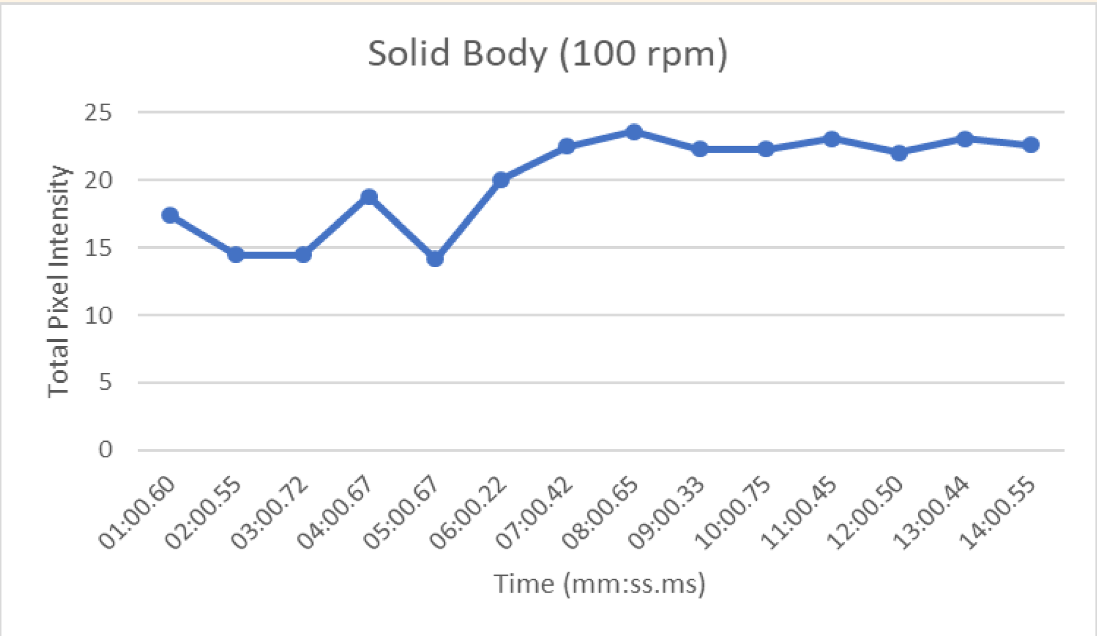

Figure 6: A plot of AACC's intensity over time for solid body rotation. Fourteen samples were taken in the span of 14 minutes.

FUTURE WORK

- Experiments should be repeated with a better control for the flow velocity. This could help the apparatus run longer for better centrifugation. Flow control valves for fine-tuning may help.
- An improved method of evenly distributing the titanium dioxide powder may be sought out. Experimental results are difficult to compare without one.
- The inner ring should be investigated for damage. LabView run-time data led to the belief the inner ring was malfunctioning and only gliding along with the outer cylinder's speed.
- Search for ways to keep powder uniformly distributed within the water reservoir. Quick settling rates result in significant amounts of powder settled at the bottom of the bucket.

ACKNOWLEDGEMENTS

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