Sensor for Monitoring Pneumatically Conveyed Coal

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Introduction

Problem statement:

Develop a sensor for measuring mass flow rate of pneumatically conveyed pulverized coal inside steel pipelines. This sensor is designed for use at PacifiCorp's Huntington Power Plant, where coal particles are 0.07 to 0.10 microns in diameter, and the inner pipe diameter is 20".

Sensor targets:

- Measure relative coal mass flow between pipes. Ideally, obtain quantitative mass flow rates and flow velocities for each pipe.
- Measure mass flow within 10% of true flow rate, which is the industry standard.
- Exhibit high durability, as milled coal is abrasive and wears down traditional probe sensors within months.
- Cost effective, less than $4000 per pipeline.

Design Method:

- First, electro-capacitance (EC) and optical sensors were determined to best fit the sensor targets as they last longer than current conventional alternatives and do not require repairs.
- Next, a prototype was designed with plastic pipe to determine if EC or optical sensors were preferred.
- Then, numerical modeling was investigated to inform the sizing of the electrodes for EC. And rule out the optical sensor.
- Finally, the prototype with metal pipe was constructed, and the sensor outputs were close to expectations using a vertical test assembly.

Measurement Principle

- Two copper electrodes are placed within the pipe, forming a capacitor.
- Capacitance is proportional to the amount of coal in the pipe.
- Capacitance is measured using a capacitance to digital (C/D) chip.
- Placing two sensors in series allows for velocity measurement from time of flight (ToF) between sensors.

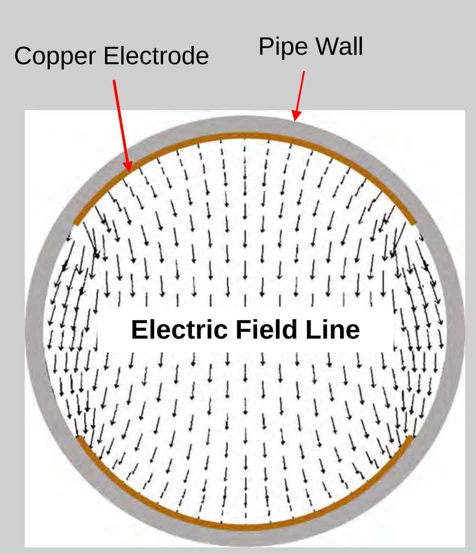

Figure1: courtesy of C G Xie et al 1990 Meas. Sci. Technol. 1 65 with modifications by John Fisher.

Theoretical foundations

$$C \propto \frac{V_{\%,coal} A}{d}$$

$$\dot{m} = \rho_{coal} V_{\%,coal} v A_{pipe}$$

- C, measured capacitance [F]
- d, distance between sensor electrodes, [m]
- A, area of electrodes [m2]
- $V_{\%coal}$, volume percentage of coal in pipe [unitless]
- ṁ, mass flow rate [kg/s]
- ρ, density of coal [kg/m3]
- v, velocity of coal flow [m/s]

Testing methods and prototypes

- Horizontal testing
- Vertical drop testing
- Mediums: talc, sand, pulverized coal
- Acrylic prototype
- Stainless steel prototypes
- Using two sensors in series to measure velocity

Testing rig

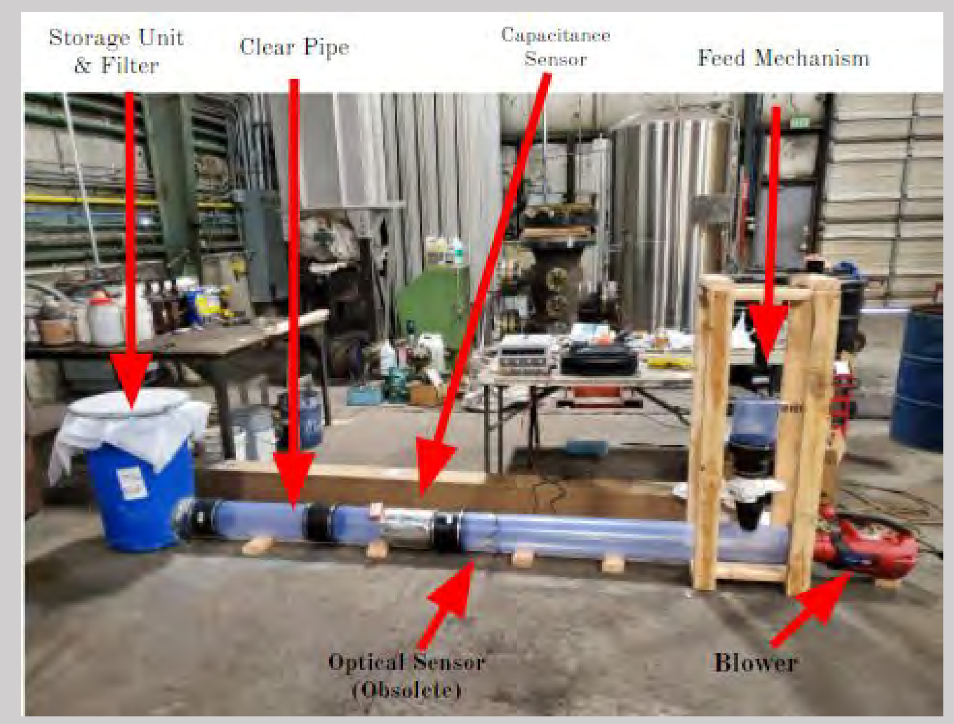

Figure 2: Horizonal Testing rig set up in the Lab

Metal pipe prototypes

Figure 3: Copper electrodes before insulating layer applied

Figure 4: Vertical test assembly with both sensors

Figure 5: Nordbak Insulator full cover. Nordbak is a 100% solids epoxy that contains ceramic beads to provide abrasion resistance.

Figure 6: RTV Insulator with tile lining. RTV is room-temperature-vulcanizing silicone that has low shrinkage, no deformation, favorable hardness, and high-temperature, acid, alkali, and ageing resistance.

Testing results

- Experimental results match computational predictions.
- Source of signal noise determined and reduced.

Figure 7: Sensor noise floor

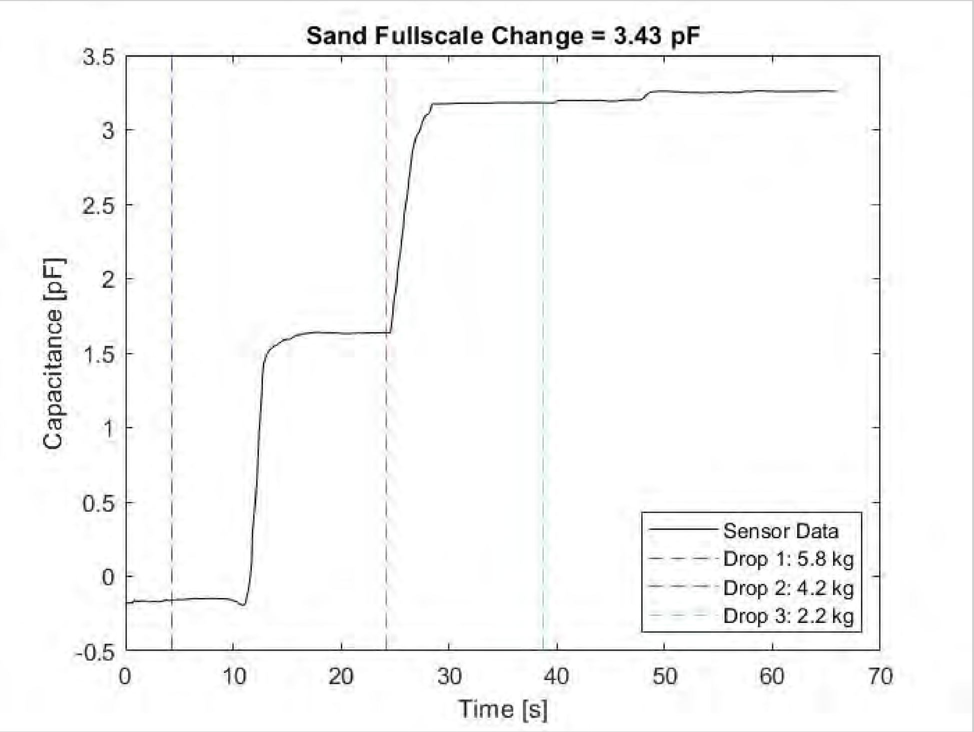

Figure 8: Sensing field was filled incrementally with sand until full to determine full scale output and corresponding mass.

Data analysis

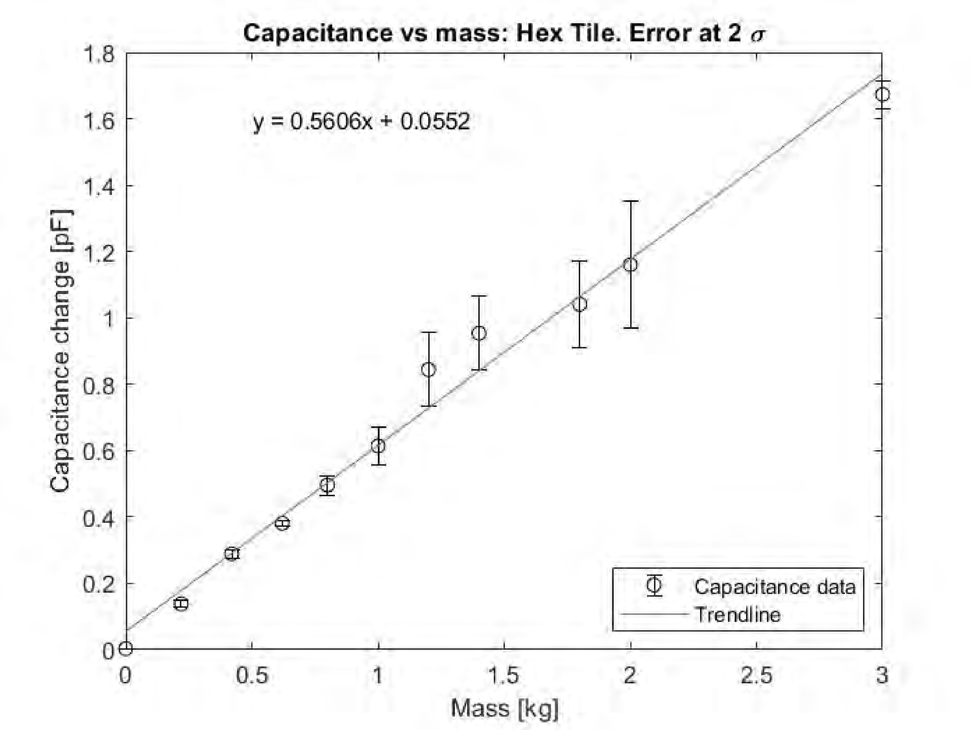

Figure 9: Results of testing varying masses of sand within the hex tile sensor prototype. As expected, the capacitance is linearly correlated to the mass of particulate in the sensing field.

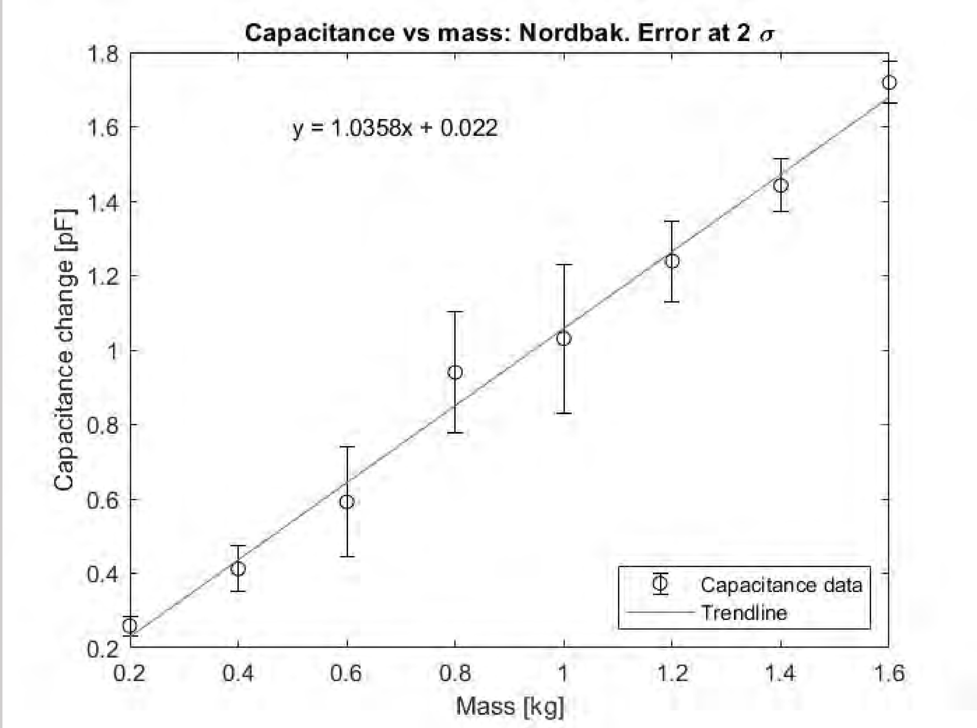

Figure 10: Results of testing varying masses of sand within the Nordbak sensor prototype. While the relationship is still linear, there exists significantly larger standard deviations in this prototype than the hex tile model. Additionally, the slope is significantly greater.

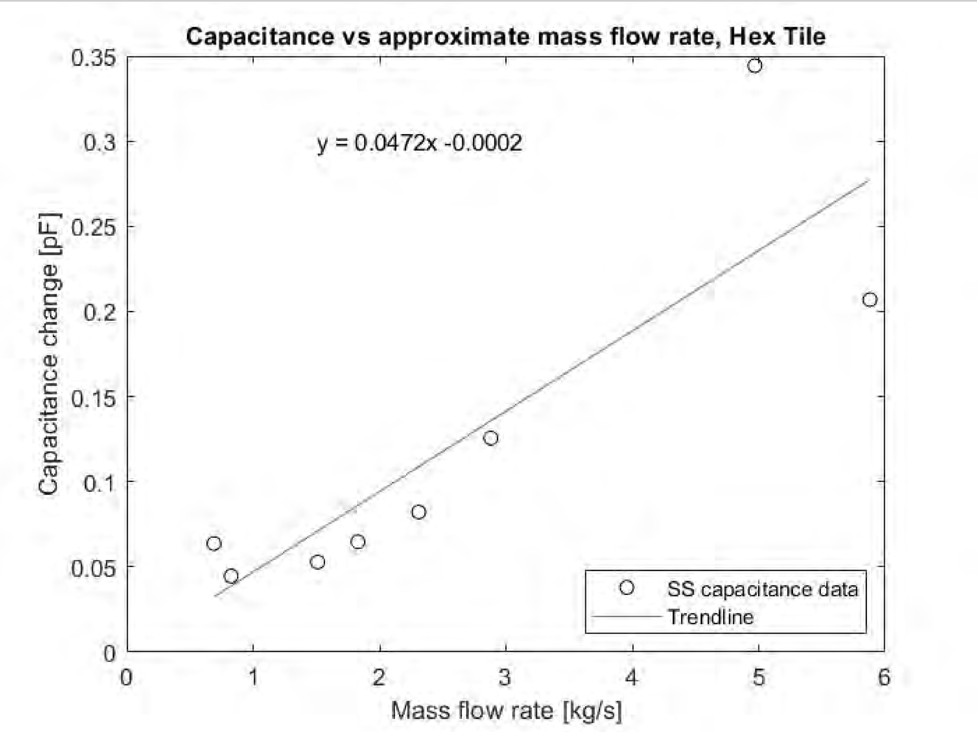

Figure 11: Steady state capacitance data compared to flow rates within the hex tile prototype. As expected, a linear relationship exists under steady state conditions. A high error is present likely due to the difficulty of maintaining steady state conditions at high feed rates.

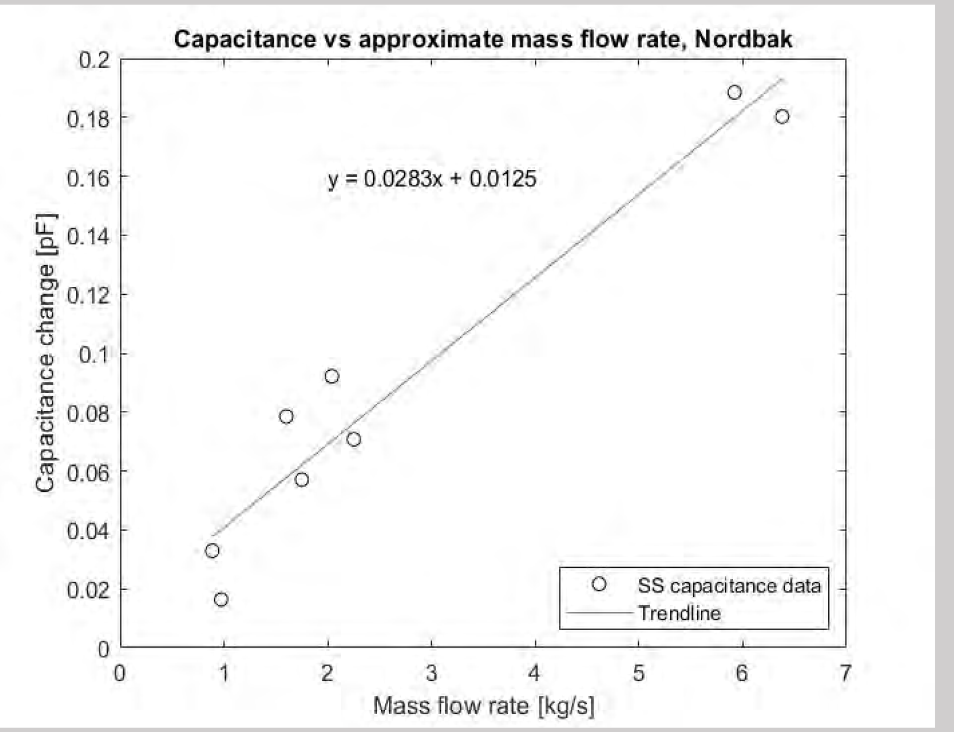

Figure 12: Steady state capacitance data compared to flow rates within the Nordbak prototype. A much stronger linear relationship exists for this model, likely due to experimenters gaining experience at maintaining steady state conditions after the hex tile prototype trials. Counterintuitively, the slope of this relationship is less than that of the hex tile model, unlike with the static mass tests.

Conclusion and final design

- Our prototype has a noise floor of ~0.0025 pF, which corresponds to a minimum detectable change of roughly 5 g under lab conditions. At our scaled flow rate, this means an accuracy of within 2.5%.
- The final design meets Pacificorp's requirements for accuracy, cost, wear resistance, and ease of installation.