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Dielectric Mass Concentration and Moisture Sensing of Organic Powders in Industrial Sensors

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Summary: Capacitive measurement has been determined as a suitable sensing technology for flow measurement in pneumatic conveying. In a typical sensor setup, electrodes are attached to the circumference of a non-conductive pipe. The flow rate can be determined from the capacitive signals. A known drawback of capacitive sensing technology is its cross-sensitivity to moisture. Recently, a dielectric material model for pulverized organic materials has been proposed that allows the simultaneous determination of the mass concentration and the moisture from dielectric measurements. This provides a potential approach for a moisture compensation option. In this work, the sensing effect within an industrial process sensor is investigated to examine the feasibility of the approach in industrial applications.

Keywords: dielectric sensing, mass flow metering, pneumatic conveying, moisture

Introduction

Accurate mass flow metering for pneumatically conveyed powder materials is relevant for various industries. Commonly used sensing principles for this measurement are differential pressure sensors, acoustic sensors, impact sensors, microwave sensors, etc. The determination of the mass flow rate from the sensing signals is then often established from calibration measurements. Also, capacitive sensing is a possible sensing strategy. Hereby, a capacitive sensor is formed by placing electrodes around the conveying pipe as depicted in Figure 1. The capacitances of the sensors are influenced by the transport goods. The mass flow rate can then be determined from the capacitive measurement signals, e.g. using calibration-based approaches, but also with model-based techniques. E.g. recent research has shown the application of electrical capacitance tomography (ECT) [1] for this task. The principal signal processing scheme of ECT is illustrated by the block diagram included in Figure 1, which comprises the determination of the spatial relative permittivity distribution ε_r and the velocity profile v. The spatial mass concentration β_s in $\mathrm{kg/m^3}$ can be evaluated from the relative permittivity ε_r utilizing a material model to compute the mass flow rate $\dot{m}$. A relevant aspect in the application of capacitive sensing is the cross-sensitivity towards moisture. For the stated measurement problem and the sensing principle, variations in the humidity affect the capacitances and subsequently lead to measurement errors. A compensation strategy is therefore required. In [2], a material model for organic pulverized material (coal) was presented, which describes the relation between the spatial mass concentration β_s, the humidity ψ, as well as the relative permittivity ε_r and the conductivity σ. With this approach, a compensation method can potentially be realized through an impedance measurement. The approach could also be used for moisture sensing, e.g. for agricultural goods for food products, and is therefore of high interest. However, the results in [2] did not address the applicability of the process within an industrial sensor, i.e. a sensor where the electrodes for the impedance measurements are mounted on the outside of a pipe as sketched in Figure 1.

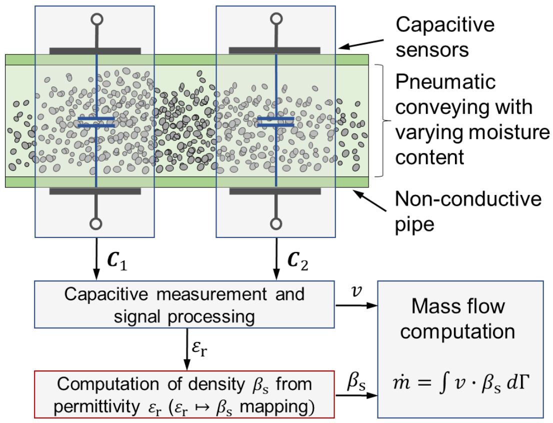

Fig. 1: Scheme of a capacitive mass flow measurement for a pneumatic conveying.

In addition, the analysis in [2] was carried out for a frequency range of several $10\,\mathrm{MHz}$. Here, a realization with an integrated impedance analyzer such as the AD5933 [3], which has an upper measurement frequency of $100\,\mathrm{kHz}$, would be preferable.

In this work, we investigate the feasibility of the proposed approach with a low-cost measure-

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ment IC for a process sensor. The analysis is carried out for pulverized coal as used in [2], and the sensor application is taken from [1].

Measurements, Modeling and Results

The analysis comprises two parts. First, the dielectric material model is characterized, afterwards, the expected impedance in a process sensor can be determined. Following [2], the conductivity σ and the relative permittivity ε_r of pulverized coal can be modeled by

$$\sigma = ((a_0 + a_1\psi)\beta_\mathrm{s})^2 \quad (1)$$

$$\varepsilon_\mathrm{r} = ((b_0 + b_1\psi)\beta_\mathrm{s})^3 \quad (2)$$

Figure 2 shows the results of a dielectric characterization of the used coal for a frequency of $85\,\mathrm{kHz}$, which lies well within the frequency range of the AD5933. The experiments have been performed following the procedure described in [2, 4], for a moisture variation between $0\,\%$ and $2.5\,\%$. The mass concentration has been varied between $\beta_\mathrm{s} = 600\,\mathrm{kg/m^3}$ and $\beta_\mathrm{s} = 700\,\mathrm{kg/m^3}$. Figure 2 depicts the probe and measurement electronics used. The probe was also used in [2]. The black dots mark the measurements. The blue and red lines are computed using the parameterized model Equations (1) and (2), respectively. As proposed, the material model provides a unique relation between the dielectric material properties, the mass concentration and the moisture concentration.

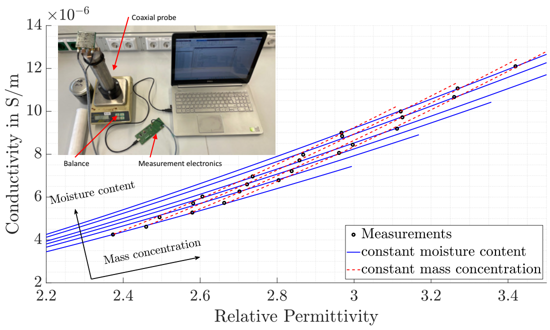

Fig. 2: Dielectric characterization of coal for different mass concentrations and different moisture content.

The parameterized material model for the relative permittivity and the conductivity is then used to evaluate the expected behaviour of the measurement impedance $\underline{Z}$. This part of the work was carried out by means of a COMSOL simulation for the sensor geometry of the sensor presented in [1]. Figure 3 depicts the behaviour of the impedance. The model is also included in the figure. Two electrodes are placed at the bottom side of the sensor pipe, and the entire pipe is filled with coal. Due to the non-conductive pipe, as depicted in Figure 1, the impedance between the electrodes is capacitive. Yet the result shows a significant variation of the conductivity and the phase for the simulated variation of the mass concentration β_s and the moisture ψ, which are well within the measurement range of the AD5933. The results therefore show that the mass concentration β_s and the humidity ψ can be sensed using an impedance measurement in an industrial sensor setup.

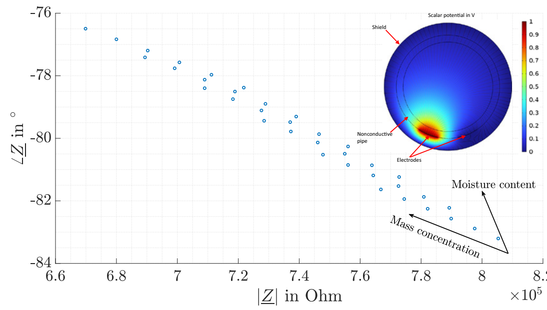

Fig. 3: Simulated impedance $\underline{Z}$ for an industrial sensor setup with the determined dielectric material model.

Conclusion

In this work, the feasibility of joint mass concentration and moisture sensing of coal powders in industrial sensors was presented. The final paper will include a more detailed analysis of the approach, a discussion of the determination of β_s and ψ from the impedance and an uncertainty analysis.

Acknowledgment

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