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Versatile impedance sensor for multiphase flow monitoring

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Summary:

This paper presents a versatile impedance sensor in a way that can be used in multiphase flow applications. The sensor measures the electrical parameters of flowing media. It can be deployed distributed along flowlines to perform real-time multiphase flow characterization. The sensor was evaluated against commercial references and further applied fluid-dynamics investigation.

Keywords: multiphase flow measurement, impedance sensor, distributed sensing

Introduction

Multiphase flow is a recurrent topic and is commonly founded in various industrial applications. For instance, in the oil and gas industry, fluids such as water, oil and gas stream typically in pipes or vessels, forming a multiphase flow mixture. For many years, scientists and engineers have extensively investigated the phenomena by performing experiments under controlled conditions to support the validation of flow models and provide data for validating computational fluid dynamic (CFD) codes, where pilot-plant studies are typically used for scaled-down flow simulation of large-scale circuits and components. However, new challenges emerged with the required energy transition, where carbon capture and sequestration (CCS) or geothermal source of energy, making further investigation necessary to understand a new type of phenomena, such as methane hydrate formation and flow at high concentrations of CO2, among others. Yet, all flow meter technologies have limitations, and most have a tough time with the multiphase flow. The fluid dynamic characteristics of the mixture are highly complex and, to a large degree, are still not characterized by modern-day fluid dynamic models [1].

Current-in-use equipment is based on measurement techniques such as electrical impedance, ultrasound, and ionic sensors (e.g., x-ray and ɣ-ray). However, none has universal applicability; some have considerable drawbacks and may fail in particular practical situations. Furthermore, installing many of them in small-scale experiments running at university laboratories and research centers is improbable due to the cost of equipment and infrastructure, making it even more challenging to access information. In this fashion, this work explores the development of versatile impedance sensors to achieve a broader application range compared to single modalities techniques, contributing to a more universal application than those currently in use. As a step towards the further development of sensor technology, we describe a dual-modality electronic being able to simultaneously evaluate the conductive and the capacitive component of the flowing media over a broad range of values and at high repetition rates in real-time.

Phase fraction measurement in fluids

Electrical impedance measurement is a common tool for characterizing the electrical properties of materials and substances. In process diagnostics, the measurement allows individual phases to be distinguished from each other based on their specific electrical properties (e.g., conductivity and permittivity).

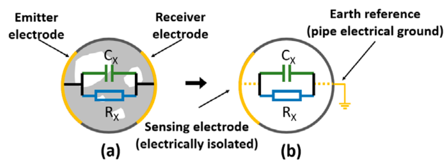

Fig. 1. Simplified electrical model for fluid mixture and capacitance and resistance measurement to earth ground reference.

Figure 1a depicts the equivalent low-frequency (up to a few MHz) circuits for a homogeneous mixture which is given by the parallel connection of a capacitor and a resistor between two electrodes (emitter and receiver). Fig 1b shows the connection topology considering a sensing electrode measuring the parameters to the common ground electrode, which is very common for some types of sensor geometry.

The measurements are carried out with the help of a measuring cell or probe designed for a determined application. Thus, the phase fraction can be estimated using sensor calibration curves, electrical mixture models, and data fusion algorithms [2].

Dual Modality Impedance Sensor

In this work, the sensor was conceived to be low-cost and easy to handle, so a number of them can be installed along a flow loop to support fluid dynamics investigation.

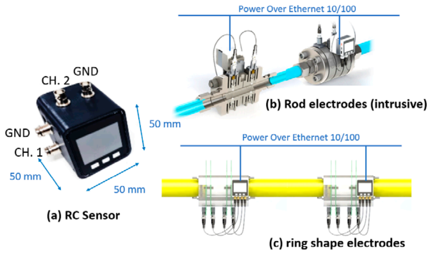

Fig. 2. (a) RC Impedance sensor; (B) distributed in a high-pressure system using intrusive electrodes; (b) distributed in flow lines using non-intrusive electrodes.

An embedded real-time system controls the sensor electronics (Fig. 2a). The sensor comprises two distinct circuits to measure capacitance and resistance parameters to the ground-earth reference. This topology was chosen to reduce the number of electrodes required because the sensor's body is made of metal to operate in conditions where the temperature and pressure are elevated (Fig. 2b). Different probes, such as rod sensors and non-intrusive ring shape electrodes, can be used (Fig. 2c). The sensor uses two channels to obtain flow velocity applying cross-correlation or specialized flow feature extraction algorithms.

The measurement type selection (R or C) is achieved by an analog switch that also commutes the measurement channel (Ch.1 or Ch.2). In addition, to investigate fast events that occur on the multiphase flow phenomena, it was designed to deliver high sensitivity at high-speed measurements. Therefore, the sensor can measure both R and C values in both channels at a repetition rate of 1000 samples per second/parameter/channel. The sensor acts like a server and continuously streams the data to the clients in a bidirectional communication through a WebSocket protocol, providing full-duplex communication channels over a single TCP connection. The sensor is powered along with data on twisted-pair Ethernet cabling. The information can be sent directly to a personal computer or a server containing services to process the data automatically and make the information available to many clients in real-time (Fig 3).

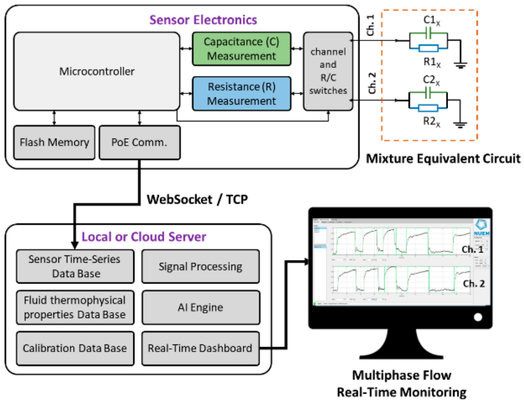

Fig. 3. Measurement components: Sensor electronics and cloud server.

Experimental Evaluation

In this work, the sensor was first evaluated by measuring commercial resistors and capacitors in a range of 0.5 ohms up to 1k ohm and 1.2 pF to 1 nF. The results show a deviation within 0.5% against reference values. As a second test, the sensor was applied to measure an oil-water mixing test. The pipe segment was filled with oil and water. An impeller mixed the phases for a short time, and the sensor monitored the separation process, as depicted in Fig. 4b.

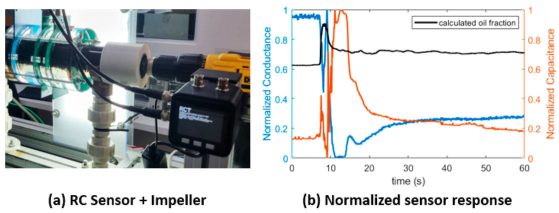

Fig. 4. (a) Experimental setup; (b) normalized conductance (blue), normalized capacitance, calculated oil fraction (black).

Conclusions

The sensor electronics were presented and evaluated. The system is able to simultaneously determine the capacitive and conductive components of fluids showing reasonable accuracy and fast response. Future work will further validate the phase fraction measurement based on resistance and capacitance measurements.

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