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Development of a capacitive sensor system for gas-liquid flow monitoring and application in hazardous areas

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Summary:

Sensors for the measurement of advanced two-phase flow parameters (besides temperature and/or pressure) in production and transportation of oil and gas are required for monitoring and control purposes of plant and equipment. This requirement is also pushed by the current digitalization trend in industry, where sensors play a pivotal role as reliable source of data. This work presents a capacitive sensor system which can be applied in industrial environment at hazardous areas. The sensor was designed to comply with explosion safety standards whilst its electronics was developed in order to support network connections. Three pair of sensors were successfully installed in different positions of a 6-inch test facility of an oil company to monitor crude oil and natural gas two-phase flow evolution along the pipe.

Keywords: Oil and Gas, Two-phase flow, Resonant Frequency, Capacitive Sensor, Explosion safety

Introduction

The simultaneous flow of oil and gas in pipelines is a common occurrence in the petroleum industry [1, 2]. Due the recent increase of oil offshore exploration and production, sensing technologies have been widely developed in order to monitor various processes in petroleum production, such as phase fractions and phase velocities for the effective operation of its equipment and pipelines [2, 3]. Several measuring techniques to investigate two-phase flows have been proposed and tested in the past [4, 5]. However, most of them have been only applied to laboratory test conditions using model fluids. The use of real fluids in industrial environment requires that the sensing solutions are able to safely operate in potential explosive atmosphere. In this paper, we introduce a capacitive sensor which was deployed and tested in an industrial test facility running real fluids, i.e. natural gas and crude oil.

Sensor

In this work, the sensing principle is based on the interaction of the flowing media and the electric field between the sensing rod and the grounded metallic sensor body (Fig. 1) which changes the measured electrical capacitance of the equivalent circuit. Once both gas and liquid are non-conducting materials, the equivalent circuit of flowing media can be represented as a capacitor from the sensing rod to the grounded pipe wall. The resonant effect of LC circuits is used to determine the unknown capacitance given by

$$f_{\text{sensor}} = \frac{1}{2\pi\sqrt{L\cdot\left(C+C_{\text{sensor}}\right)}}\,. \qquad (1)$$

The circuitry is based on FDC2214 (capacitive sensing IC) and MCP430 (microcontroller). The electronics is mounted inside an explosion-protected enclosure (Fig. 1), providing reliable protection for flammable environment. Furthermore, typical Zener barrier is deployed for feeding the excitation electrode (metallic rod) in order to comply with intrinsic safety of electrical installations (Fig. 2).

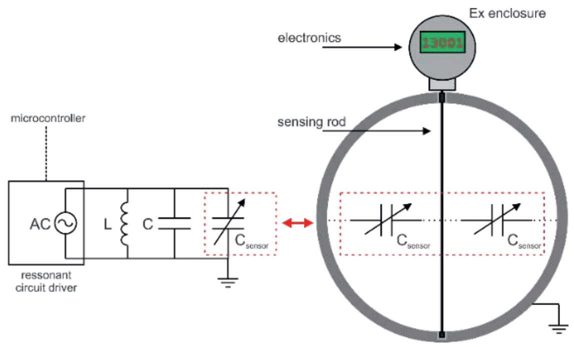

Fig. 1. Measurement schema for LC resonant circuit driver.

System Evaluation

The system was deployed at the Núcleo Experimental de Atalaia (NEAT), located in Aracaju, Sergipe, Brazil, which is an experimental test center and part of Petrobras Research and Development Center (CENPES). NEAT employs crude oil (156 cP at 40ºC) and natural gas as working fluids. A simplified diagram of the test site is shown in Fig. 2. The gas line is supplied from a compression unit and the oil from tanks. The multiphase test flow loop consists of approximately 200 meters (in form of a "U" with 100 m in which segment) and six sensor nodes are disposed in pairs in order to further extraction of parameters such as bubbles translational velocity. Fig. 3 depicts a picture of the installed twin sensor with a pressure/temperature meter. Three different locations were chosen to monitor the flow evolution along the pipe.

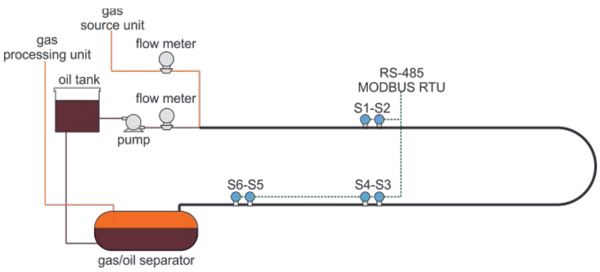

Fig. 2. Simplified overview of NEAT-Petrobras experimental facility and main components.

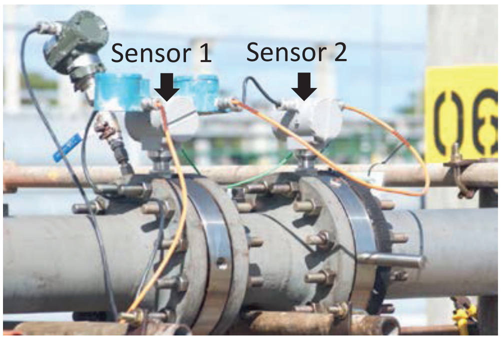

Fig. 3. Pair of sensors installed at 6" pipe flanges (ANSI B16.5 Class 300#) at NEAT-Petrobras.

Results and Discussion

Several experimental conditions were investigated. Here we report only one experiment with superficial velocities of 0.5 m/s for both gas and liquid phases. The superficial gas velocity was corrected by the pressure difference between reference measurement (at Coriolis) and the experimental point. In Fig. 4 one can observe the typical unit cell structures on the signal (liquid slugs and elongated gas bubbles) of the so-called slug flow. The study of unit cell parameters is directly related with the development of low-order models, which in turn are applied by engineers for design and during operation of flow lines. Hence, detailed analysis of flow behavior is pivotal to better description of flow which in turn will be applied in better flow models and predictions.

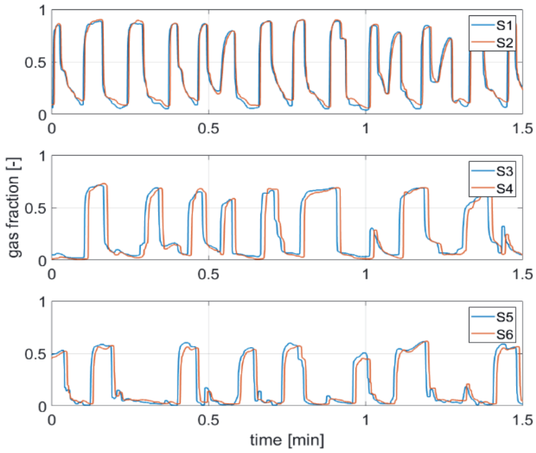

Fig. 4. Evolution of time series for an experimental gas and liquid superficial velocities of 0.5 m/s and 0.5 m/s respectively.

Conclusion

A capacitive sensor was developed and applied for two-phase flow investigation in industrial experimental facility with hazardous areas. Preliminary results have shown the capability of the sensor to investigate two-phase flow at high temporal resolution with minimum intrusiveness in an industrial environment running with real fluids (crude oil and natural gas). The development of sensor design to comply with a potentially explosive atmosphere was successfully tested. Hence, the developed measuring system may be applied to systematic flow studies at experimental conditions similar to real applications.

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