proceedings

Proceedings

Multi-Electrode Capacitive and Inductive Sensing Applied to Level Measurement of Multiphase Fluids †

Avner Ostrovski Säuberlich [1,2], Aluisio do Nascimento Wrasse [1,2], Eduardo Nunes dos Santos [1,2] and Marco José da Silva [1,2,*]

[1] Federal University of Technology—Paraná (UTFPR), Graduate Program in Electrical and Computer Engineering (CPGEI), 80230-901 Curitiba-PR, Brazil; avnersauberlich@gmail.com (A.O.S.); aluisio@alunos.utfpr.edu.br (A.d.N.W.); e.n.santos@ieee.org (E.N.d.S.)

[2] Federal University of Technology—Paraná (UTFPR), Multiphase Flow Research Center (NUEM), 81280-340 Curitiba, Brazil

* Correspondence: mdasilva@utfpr.edu.br; Tel.: +55-41-33104709

† Presented at the 6th International Electronic Conference on Sensors and Applications, 15–30 November 2019; Available online: https://ecsa-6.sciforum.net/.

Published: 14 November 2019

Abstract: Multiphase gravity separators are widely used in the petroleum industry to separate the produced stream of oil, water and natural gas into pure (single-phase) streams. These equipment work based on the density differences of each fluid which tend to settle into layers when dwelled for some time in the separator. It is fundamental to monitor the levels of these phases inside the vessel, so that this information can be used in control strategies in order to increase the efficiency and safety of the process. In this work, we present a novel multiphase level sensor based on capacitance and inductance measurements of planar multi-electrodes and multi-coils. The sensor is low-cost, fast and does not apply ionizing radiation, being therefore simple to operate. The prototype sensor was constructed in standard printed-circuit board (PCB) technology and highly sensitive capacitance and inductance measurements are acquired with modern integrated circuit devices. Since the capacitive sensor readings depend on the water salinity, we perform simultaneous inductance measurements to compensate for such dependence. We have tested the prototype from two different approaches: varying the water salinity and for different water/oil mixtures. Preliminary results have shown the capability of the sensor to differentiate each one of the produced fluids, i.e., salty water, oil and gas, as well as the interfaces between them. A 16 electrodes capacitive-only sensor prototype was also built and tested.

Keywords: level sensor; capacitive sensing; inductive sensing; multiphase separator; petroleum industry

1. Introduction

Multiphase gravity separators are present in processing units of oil production facilities to separate the stream from reservoirs (normally composed by gas, oil and water) into pure (single-phase) streams. The operating principle of such equipment is based on the density differences of each fluid which tend to settle into layers when dwelled for some time in the separator. Figure 1 illustrates the basic scheme of a multiphase separator operation. The process of monitoring the level of fluids in multiphase separators is indispensable for optimal operation of such equipment. The information about the substance level within the separators are used as control variables in order to regulate the flow of the incoming stream and also the output flow of the single-phase compounds obtained from this process. Hence, optimum process parameters may be achieved. Through this control, it is possible to perform an efficient separation of the different substances in the tank. Hence, it shall avoid the situation of the water extracted from the process containing a high oil concentration and the oil extract only carrying small amounts of water, as a result of non-adequate incoming and outgoing flow control, which could compromise environmental regulations for the water stream or compromise the refining processes of the oil stream.

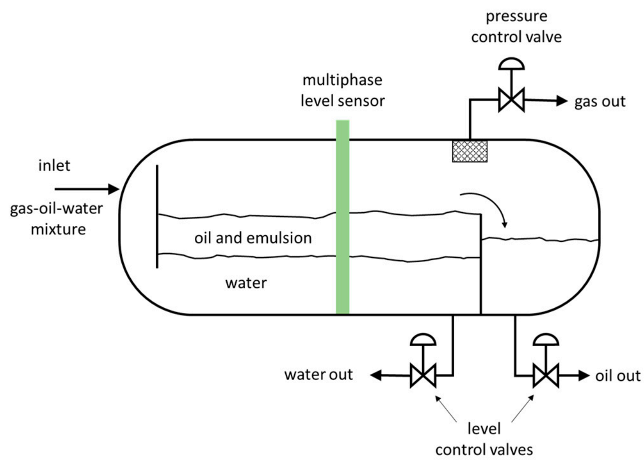


Figure 1. Multiphase separator schema.

In order that the flow and level to be properly controlled, it is necessary to use appropriate sensing systems, so that the levels reading of different phases within the separators is accurately monitored. There are different sensing technologies for multiphase level monitoring, based, for instance, on ultrasound, ionizing radiation and electrical impedance [1–4]. However, none can be seen as general and each solution presents some disadvantage.

In this work, we present a novel multiphase level sensor based on capacitance and inductance measurements of planar multi-electrodes and multi-coils. The sensor described here is able to distinguish each substance (gas, oil and water) based on the measurement of electrical capacitance and inductance. The technology used to measure the variation of capacitance and inductance in the sensor is based on the resonance frequency variation of a circuit composed of the sensor capacitors/inductors of variable values (present on the sensing area), in parallel with inductors/capacitors of fixed values (present on the electronics) [5]. As the sensors have their values modified by the different substances surrounding them, the different capacitor-inductor circuits formed also have their resonance frequencies modified. This technique has a great accuracy and good noise immunity.

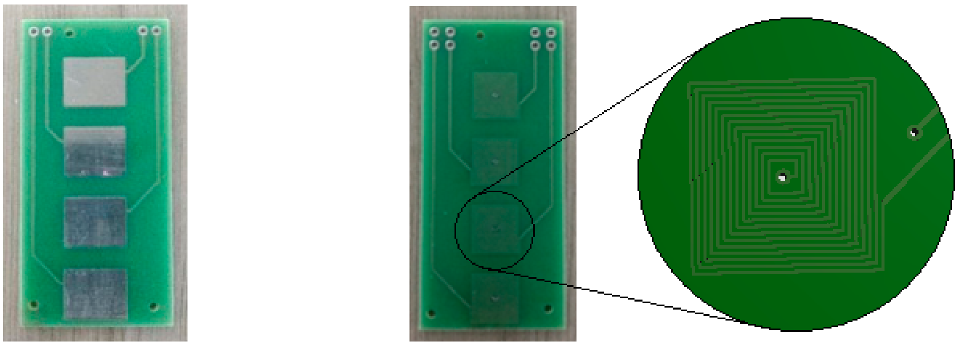
The hybrid technology presented (capacitive and inductive sensing) enables the sensor to monitor substances with higher electrical conductivity values, for instance brine. In pure capacitive measurements, salinity changes highly influence capacitance readings and sometimes may cause short-circuit in the sensor electrodes. In addition, the planar geometry adopted in the coils reduces the impurities accumulation in the sensing region.

2. Materials and Methods

Capacitive and inductive PCB prototypes were designed for preliminary tests in laboratory conditions. Figure 2a,b depict these devices, in which the electrode and inductor shape were built with same geometry intended for latter tests in a prototype separator vessel.

Posteriorly, a second sensor design composed by 16 capacitive sensors (Figure 3) was idealized to be installed in a prototype transparent separator (Figure 4). In this case, the fluids within the separator may be investigated only by capacitance measurements, due the absence of high-conductivity water. In this paper, we only report static measurements for this prototype.

In Figure 3, the integrated circuits for capacitive measurements are situated in the top of the PCB with all its electronics for controlling, processing and sending the measured data to an external computer. At the bottom are the 16 electrodes (measuring 9 mm × 11.5 mm each), referring to the 16 channels responsible for capacitance measurements of the different substances and interfaces present in the separator.



(**a**) (**b**)

Figure 2. (**a**) Capacitive prototype printed-circuit board (PCB); (**b**) Inductive prototype PCB with detail to coil geometry.

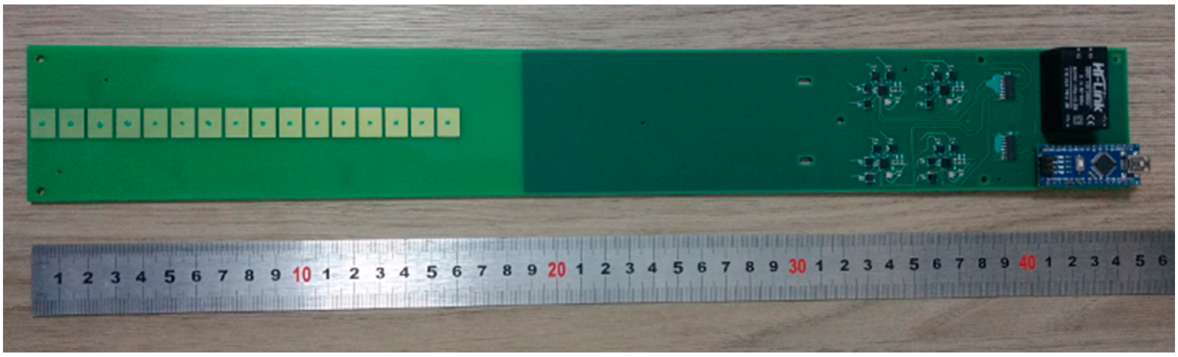


Figure 3. Capacitive prototype PCB.

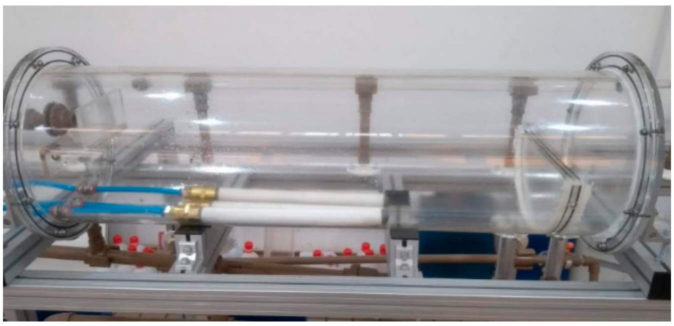


Figure 4. Federal University of Technology—Paraná (UTFPR)'s prototype horizontal separator.

3. Results and Discussions

3.1. Preliminary Tests

We performed several experiments with the PCB presented in Figure 2a,b. The main ones refer to the monitoring of their average capacitance and inductance in water with different values of electrical conductivity (Figure 5) and mixtures with different proportions of saline water and oil (Figure 6). The standard deviations (σ around 0.05 pF) are too small to appear in the figures.

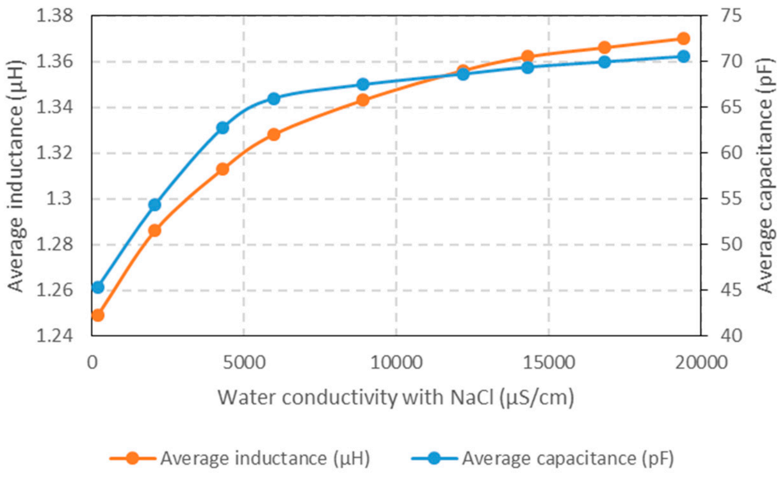


Figure 5. Capacitance and inductance on water with different values of electrical conductivity.

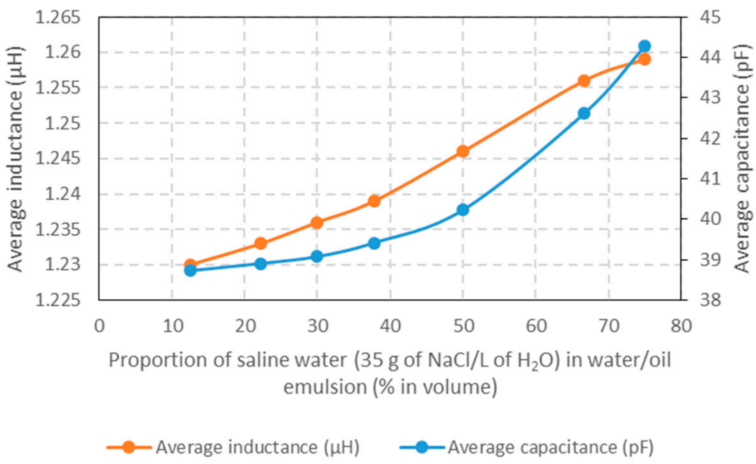


Figure 6. Capacitance and inductance on emulsions with different proportions of saline water and oil.

Both measured values capacitance and inductance vary with the salinity and the water concentration in water/oil mixtures. In this way, it may be possible to convert these two measured values into the two parameters (conductivity) salinity and water concentration. If only a single parameter was obtained, no correction would be possible. These promising results show that the combination of capacitance and inductance sensing has the capability to be employed in real applications of level measurement in gravity separators running with brine and oil.

3.2. Sixteen-Channel Capacitive Level Sensor

As previously mentioned, a prototype separator (Figure 4) is intended to be instrumented with the novel sensor. Therefore, a 16-channel capacitive-only sensor was built. In order to verify the behavior of the sensor measurement and obtain capacitive values as function of the relative electrical permittivity of the medium (ε_r), an immersion experiment was carried out of its 16 measuring electrodes in different known substances, i.e., ambient air ($\varepsilon_r = 1$), mineral oil ($\varepsilon_r \cong 2.5$), 2-propanol ($\varepsilon_r \cong 20$), ethylene glycol ($\varepsilon_r \cong 40$) and deionized water ($\varepsilon_r \cong 80$); whose relative electrical permittivity values were taken from references [6]. The graph of Figure 7 shows the capacitances of all the 16 electrodes (Figure 4) for each tested substance, confirming their expected linearity in relation to the electrical permittivity. As expected, each sensing electrode presents its own linear trend, which may be compensated for by calibration routines.

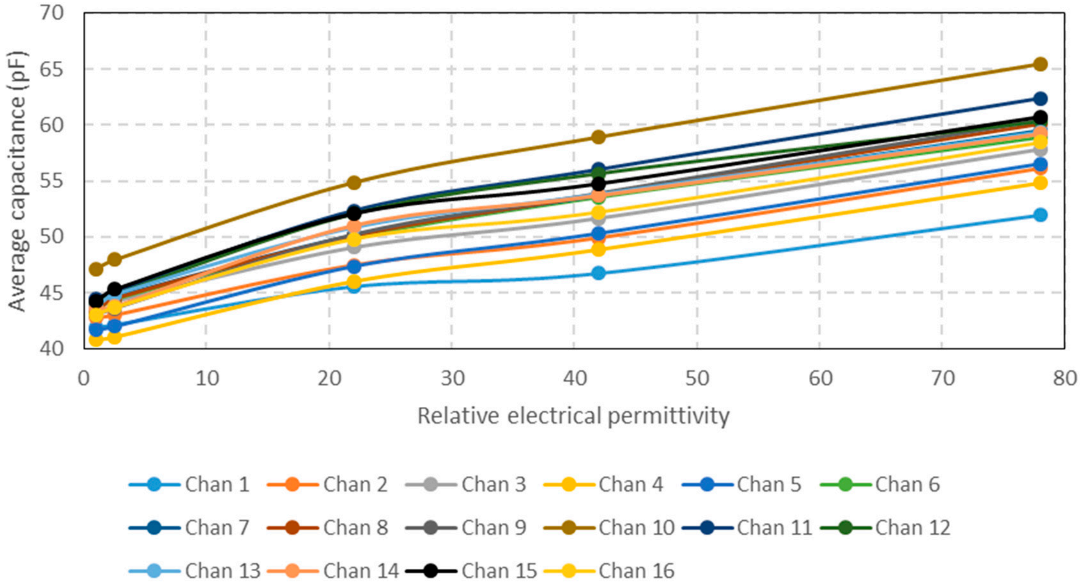


Figure 7. Capacitance readings of each of the 16 electrodes for different substances (electrical permittivity values).

In order to convert capacitance readings into current substance present in the surrounding of each electrode and thus be able to identify the level of each substance in an oil/water/gas separation process, the following routine was applied. Since each type of substance that surrounds the sensor channels causes the measured capacitance to be between a specific range of values, through individual analysis of each singe electrode, it was possible to program the microcontroller to identify which type of substance that is present in each sensor region. This routine must be adapted for the substances involved. In order to have visual and more intuitive information of the sensor monitoring, an application was developed in the Elipse E3 supervisory software, in which, based on the calibrations and data processing from the electronic circuit of the device, illustrates to the user in real-time the levels of fluids present in the reservoir. The image presented by Figure 8 shows the visual information of the interfaces monitoring between different fluids by the developed sensor.

For future works, it is possible to change the constructive layout of the device, which is not only capable of reducing the distances between the measuring circuits and their sensor terminals (decreasing interferences, noises and parasite capacitances), but can also help to increase the number of sensor measuring channels.

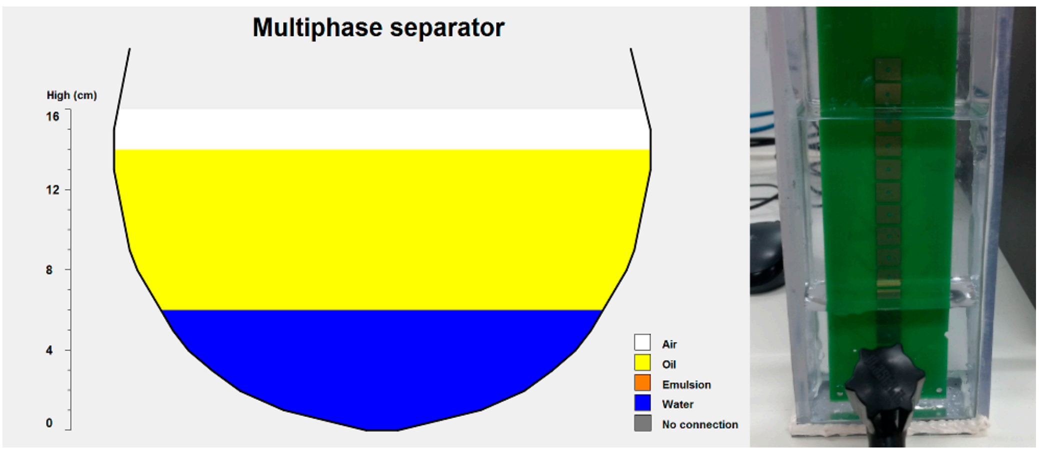


Figure 8. Sensor wrapped in air, oil and water.

4. Conclusions

We have presented preliminary measurements of capacitance and inductance which may be applied for the simultaneous determination of water salinity and concentration of water/oil mixtures. This will be followed in future development in our group.

Furthermore, we have introduced a 16-channel capacitive-only prototype which has been successfully applied to monitor the (as yet) static level of tap water, oil and air. This sensor presents good linearity for permittivity measurements and a dedicated level measurement routine was developed and tested. In the future, we aim to apply more elaborated routines to automatically compensate for salinity deviations (based on inductive readings). For the moment, this is good enough to control the prototype separator. Hence, the dynamic behavior of the substances inside the vessel may be properly monitored which in turn will allow for the optimal control of such equipment.

Author Contributions: Conceptualization, M.J.d.S.; methodology, A.O.S., E.N.d.S. and A.d.N.W.; software, A.O.S.; investigation, A.O.S., E.N.d.S. and A.d.N.W.; writing, A.O.S., E.N.d.S., A.d.N.W., and M.J.d.S.; supervision, and M.J.d.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by following Brazilian institutions: CENPES/PETROBRAS, CAPES and CNPq.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Jaworski, A.J.; Dyakowski, T.; Davies, G.A. A capacitance probe for interface detection in oil and gas extration plant. *Meas. Sci. Technol.* **1999**, *10*, L15.
2. Meng, G.; Jaworski, A.J.; Kimber, J.C.S. A multi-electrode capacitance probe for phase detection in oil-water separation processes: Design, modelling and validation. *Meas. Sci. Technol.* **2006**, *17*, 881.
3. Meribout, M.; Naamany, A.A.; Busaidi, K.A. Interface Layers Detection in Oil Field Tanks: A Critical Review. In *Expert Systems for Human, Materials and Automation*; Intech. Open: London, UK, 2011; doi:10.5772/17166.
4. Yang, W. Sensors and instrumentation for monitoring and control of multi-phase separation. *Meas. Sci. Technol.* **2006**, *39*, 178–184.
5. Texas Instruments. FDC1004: Basics of Capacitive Sensing and Applications. Available online: http://www.ti.com/lit/an/snoa927/snoa927.pdf (accessed on 22 October 2019).
6. Da Silva, M.J.; Schleicher, E.; Hampel, U. Capacitance wire-mesh sensor for fast measurement of phase fraction distributions. *Meas. Sci. Technol.* **2007**, *18*, 2245–2251.