11th International Conference on Green Energy & Environmental Engineering (GEEE-2025)
Proceedings of Engineering & Technology – PET-Vol 94, pp. 232-243

Conductance probe approach for gas retention measurement: critical review and design perspective

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***Abstract*— Multiphase flows are ubiquitous in industrial processes such as those in the energy, chemical and petroleum sectors and accurate characterization of gas holdup in these systems is crucial for process optimization and energy efficiency. This study provides a review of gas holdup measurement techniques in two-phase flows with a particular focus on conductance probes that thanks to a multi-electrode arrangement in coaxial tubes allow real-time measurement of local variations in the conductivity of the gas-liquid mixture. However, traditional measurement systems are limited by nonlinearity and calibration dependence. The integration of advanced technologies such as neural networks and adaptive filters overcomes these challenges and improves measurement accuracy under complex conditions. The measurement chain proposed in this study combines these probes with electronic circuits and data processing software allowing real-time analysis and optimization of system performance. This research provides a flexible and adaptable solution for multi-phase industrial environments, ensuring more accurate and reliable measurement of gas retention.**

***Keywords*— Two-phase flow, gas retention, conductance probe, coaxial tubes.**

I. INTRODUCTION

Two-phase flows involving multiple phases (gas, liquid, solid) are essential in fields such as chemical processing, oil production, and nuclear engineering. [1], [2] A key parameter is gas holdup, defined as the ratio of gas volume to the total volume of the mixture, which influences pressure losses, heat transfer, and drag. In the oil industry, the use of coaxial tubes improves fluid management and increases hydrocarbon production. Flow analysis in this complex geometry is crucial for optimal and safe sizing of facilities.

Gas holdup measurement uses various technological approaches adapted to different contexts. Some methods rely on probes that directly capture flow characteristics but can be influenced by interaction with the fluid. Other techniques, such as ultrasonic, optical, or nuclear technologies, allow for remote measurements, ensuring more precise flow observation. These modern approaches offer rapid and reliable data acquisition, with great flexibility to adapt to various experimental and industrial conditions.

Flow regimes and gas holdup are fundamental elements for characterizing two-phase flows. Their measurement is becoming increasingly essential in many industrial sectors, particularly in the physical, chemical, petroleum, and nuclear fields. These parameters are essential to ensure the efficiency and performance of operating systems. The measurement of two-phase flow parameters such as flow regime and gas holdup is of considerable importance and plays a key role in characterizing the hydrodynamic behavior of these gas-liquid two-phase systems. [3]- [5]

ISSN: 1737-9334

However, current gas holdup measurement techniques have significant limitations, particularly under dynamic and complex flow conditions. Conductance probes, widely used for their simplicity and ability to provide real-time data, are often affected by rapid variations in flow regimes, which impacts their accuracy. These challenges highlight the need for innovative and robust approaches to meet the demands of modern industrial applications.

This article provides an in-depth review of gas retention measurement techniques based on electrical conductance, with a focus on the integration of these sensors into an electronic measurement chain. The objective is to present a clear and concise state-of-the-art overview that will serve as a basis for the design and optimization of high-performance measurement systems.

II. BIBLIOGRAPHIC LITERATURE

Currently, there are no reference standards for gas holdup measurement which is essential for calculating the mixture density of two-phase flow and friction pressure drop and for analyzing the flow state in the pipe. It is difficult to measure gas holdup of gas-liquid two-phase flow due to its complexity and variability so part of this work focuses on gas holdup measurement techniques.

To ensure the efficiency and safety of systems, it is essential to use suitable measurement techniques. Among these, self-adaptive conductance probes stand out as an innovative solution for quantifying gas retention. We will examine these different approaches with a focus on the use of self-adaptive conductance probes to design a device capable of characterizing the configurations of a two-phase water-air flow circulating in coaxial tubes in the laboratory.

A. *Gas retention measurement techniques*

Electrical conductivity probes measure the conductivity of fluid using electrodes that detect the electrical current passing through the mixture. Conductivity depends on the electrical properties of the liquid and gas phases present.

Wang et al. (1991) studied the performance of dual- and quadruple-sensor probes, demonstrating their ability to accurately measure conductivity in complex mixtures. In 2012, they developed a capacitive coupled non-contact conductivity detection (C4D) sensor to measure gas holdup in stratified flows. In 2017, they refined these techniques by introducing innovative methods to improve the accuracy and reliability of void fraction measurements. [6]- [8]

Optical probes are valuable instruments for analyzing multiphase flows, using light transmission to detect the presence of bubbles and particles. Julia et al. (2005) conducted important studies on the accuracy of intrusive optical probes, highlighting how their insertion can distort bubbles, affecting measurement reliability. Studies by Sharma et al. (2012), Ma et al. (2014), and Feng et al. (2018) examine the impact of intrusive optical probes in turbulent multiphase mixtures, particularly in relation to gas holdup. Sharma et al. (2012) showed that probe intrusion disrupts bubble dynamics and affects gas holdup, while proposing methods to mitigate this impact. Ma et al. (2014) highlighted the need for improvements in probe design to reduce the effects of intrusion on phase distribution, including gas holdup. Feng et al (2018) explored advanced optical probing techniques to improve the accuracy of gas holdup measurements while accounting for probe disturbances. This research highlights the challenges associated with the intrusiveness of optical probes in flow analysis. [9]- [12]

Nuclear techniques used for fluid analysis rely on the application of ionizing radiation. The gamma-ray attenuation technique is used to study fluids by measuring the intensity of gamma rays after they pass through a sample, allowing for the assessment of density, composition, and gas retention. Kandoush et al. (1992) pioneered the application of this method to quantify gas retention in multiphase flows. Subsequently, Ghosh et al. (2007) demonstrated its usefulness for real-time monitoring of liquid levels. Liu et al. (2015) highlighted the importance of optimizing detectors to improve measurement accuracy. Kumar et al (2018) compared this approach with other non-intrusive techniques while Nazeim et al (2015) performed a new approach combining gamma ray attenuation and a multi-layer perceptron neural network (MLP) thus allowing the determination of the void fraction in gas-liquid multiphase flows. Finally Yu Zhao et al (2016) studied innovations aimed at increasing the measurement resolution by taking into account various parameters such as fluid temperature and distance from the measuring instrument. [13]- [18]

ISSN: 1737-9334

Neutron tomography is a method that generates cross-sectional images of objects by studying the interaction of neutrons with materials. Lerch et al (2003) illustrated its potential for obtaining high-resolution images of microstructure.

Kumar et al (2010) highlighted its effectiveness in observing phase interactions in multiphase systems. Brüning et al (2015) highlighted its usefulness in materials conservation, enabling the analysis of historical pieces without damage. Advances such as those by Keller et al (2017) have improved detectors and analysis techniques, improving image accuracy. Finally, Chabouh et al (2020) introduced innovative methods to optimize the analysis of fluid mixtures. In sum, neutron tomography is a key tool for non-destructive analysis, providing detailed information on the structure and composition of materials. [19]- [23]

Nuclear magnetic resonance (NMR) is an essential technique for the analysis of molecular structures, including in multiphase systems where gas retention is a key parameter. Bax et al. (1994) demonstrated its effectiveness in determining 3D protein structures, and Kainosho et al. (2006) used it to study bimolecular interactions. Trosset et al. (2008) explored its application in the analysis of polymers taking into account gas retention. Advances by Wagner et al. (2011) improved the sensitivity of measurements, while Chandra et al. (2015) highlighted its role in drug discovery. Thus, NMR is a versatile tool offering crucial insights into the structure and behavior of systems containing void fractions. [24]- [28]

Non-nuclear techniques encompass various analytical methods that do not use ionizing radiation, making them safer and less disruptive to the systems studied, particularly in the assessment of gaseous holdup.

Ultrasonic techniques are particularly effective for measuring gas retention in multiphase systems through the analysis of density variations and bubbles present. A. Addali et al (2009) studied the measurement of the gas void fraction in a two-phase gas/liquid flow using acoustic emission technology, allowing this fraction to be inferred in real time and in a non-intrusive manner.

In 2010 they explored two-phase liquid/gas flow in slug conditions, highlighting the need to monitor these slugs and measure key features to minimize disruptions in downstream processing facilities. Guan et al. (2009) showed that amplitude variations of ultrasonic signals can be used to estimate gas holdup in a non-intrusive manner. Huang et al. (2011) highlighted the use of ultrasound to quantify bubble volume in flows. Wang et al. (2013) proposed a model improving gas holdup estimation from ultrasonic data. More recently, César Yutaka Ofuchi et al. (2020) explore the use of an ultrasonic sensor to measure void fraction in an intermittent swirling water and air flow. This approach involves converting liquid film thickness measurements into an estimate of gas holdup based on the assumption of symmetrical swirling flow while Chaofan Li and Al developed a method to measure gas holdup in two-phase flows using flow noise decoupling and differential pressure. Their technique relies on the analysis of acoustic fluctuations generated by interactions between the gas and liquid phases to isolate flow noise to extract relevant data on the void fraction. [29]- [35]

Capacitance measurement techniques are essential for assessing gas holdup in multiphase systems. Geraets et al. (1987) designed a capacitance sensor to measure time-averaged void fractions in a flow inside a dielectric tube. The sensor uses a crossed helical capacitor electrode configuration with guard electrodes to reduce edge effects. Chen et al. (2005) proposed improvements for industrial applications emphasizing the importance of calibration. Johana Mohamed et al. (2011) developed an electrical capacitance tomography (ECT) method that visualizes multiphase flows in pipelines. Their approach relies on the use of electrical capacitance sensors that measure variations in dielectric permittivity inside a closed pipe, while Areeba Shafquet et al. (2010) conducted an experimental study using the electrical capacitance tomography (ECT) technique to measure gas holdup in a bubbling two-phase flow. Marcelo S et al. (2011) undertook an innovative research to design, build, and test a capacitive sensor dedicated to measuring gas holdup in a prototype natural circulation cooling circuit. More recently, Wael Ahmed et al. (2020) presented an extensive research on the evaluation of two-phase flow parameters within tube bundles, a crucial aspect for analyzing vibration excitation mechanisms and assessing the stability of bundle configurations. Finally, Feng et al. (2022) integrated capacitive sensors into real-time control systems, strengthening their industrial application. [36]- [42]

Optical or photographic techniques as non-intrusive and non-nuclear methods are particularly suitable for measuring gas holdup in two-phase systems. Geraets et al. (1987) were among the first to demonstrate the application of optical imaging to analyze liquid mixtures. Johana Mohamed et al. (2011) explored these techniques to monitor gas holdup in real time in complex flows. Wang et al. (2012) used high-speed camera imaging to study bubble dynamics providing accurate data on their size and distribution. Sharma et al. (2012)

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examined the impact of optical probes on bubble dynamics showing their ability to measure gas holdup. Zhao et al. (2016) developed light scattering to characterize bubbles allowing direct estimation of gas holdup.

Finally, Huajun Li et al. (2016) introduced optical tomography methods to analyze the internal structure of fluid mixtures. [36], [38], [7], [10], [18], [43]

Gas holdup measurement techniques based on differential pressure across devices such as Venturi tubes are widely studied due to their simplicity and effectiveness for two-phase flows. These methods allow the evaluation of void fraction by establishing a relationship between differential pressure, flow rate, and phase properties. Chisholm et al (1973) were among the first to propose empirical correlations relating pressure drop to gas-liquid phase parameters by taking into account the slip ratio. Similarly, Woldesemayat and Ghajar (2007) demonstrated the influence of flow regimes and Venturi tube geometry on the accuracy of gas holdup measurements. [44], [45]

The studies by ZEGHLOUL et al. (2020) and MESSILEM et al. (2020) focus on the use of Venturi tubes to measure pressure drop and gas holdup in two-phase flows. ZEGHLOUL et al examined pressure drop measurements in Venturi tubes installed in a vertical pipe using three types of Venturis with different diameter ratios (0.4, 0.55, and 0.75). Differential pressure sensors and conductance probes are used to measure gas holdup. The results reveal that the pressure drop increases with the liquid velocity and that the Venturi with a ratio of 0.55 offers the best correlations for two-phase flows particularly for the calculation of pressure drop and multiplication coefficients and those of MESSILEM et al on their part proposed a new correlation to improve the measurement of mass flow confirming the importance of the geometry of the Venturi and experimental parameters to obtain accurate results. The approach is based on the use of Venturi tubes associated with conductance probes, allowing to measure directly and continuously the mass flow of the flows without the need to separate the two phases. The study carried out with three diameter ratios (0.40, 0.55 and 0.75) analyzed the impact of geometry on different flow regimes (bubbly, undulating and turbulent). The parameters studied include gas holdup, pressure drop and associated time series. A new correlation for the interphase slip ratio has been proposed, providing more accurate results than existing models. The Chisholm correlation applied to the diameter ratio of 0.55 showed the best performance. This method provides a simple, reliable, and cost-effective alternative for industrial measurements. [46], [47]

The work of SAIDJ et al. (2014) and (2018) examined the characteristics of two-phase flows in pipes, using conductance probes to measure void fraction. In the 2014 study, the authors focus on slug flow in a 6 m long pipe, where they analyze the average void fraction, the lengths of liquid slugs and Taylor bubbles, as well as the frequency of structures and show that the Brauner and Ullmann model predicts void fraction well. In contrast, in the 2018 study, SAIDJ et al. explore an air-water mixture passing through a 90° bend, with void fraction measurements at nine positions. They examined an air-water mixture passing through a 90° bend observing different flow regimes and confirming that the Nicklin et al. correlation accurately predicts the velocity of structures. This work enriches the understanding of two-phase flows in complex configurations. [48], [49]

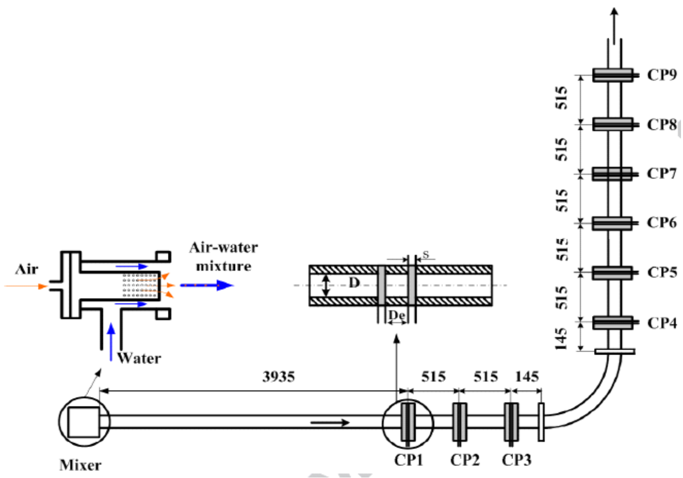

Fig. 1 Distribution of the conductance probes along the test section. [48]

ISSN: 1737-9334

In recent years, a new method for measuring gas holdup has emerged based on the use of artificial neural networks (ANNs). This innovative approach allows for processing complex data and improving the accuracy of estimates under various flow conditions. Artificial neural networks (ANNs) are capable of modeling complex relationships between input variables such as fluid characteristics and flow conditions and the desired void fraction. By relying on training with experimental data, this method improves the accuracy of estimates even in environments where traditional techniques may fail.

In 2023, work by Aryan Veisi et al validated water-air two-phase flow simulations with COMSOL Multiphysics developing an artificial neural network (ANN) model to predict gas holdups in petroleum product pipelines. At the same time, Ramy Mohammed et al designed a system for measuring gas holdup in two-phase fluids combining an 8-electrode capacitive sensor and an MLP neural network essential for the petrochemical industry. [50], [51]

III. Fundamentals of Gas Retention Measurement by Conductance

Gas holdup is defined as the volume fraction occupied by the gas phase in a two-phase flow. It is quantified by the Gas Void Fraction (GVF), expressed by the relationship:

$$GVF = \frac{V_g}{(V_g + V_l)} \quad (1)$$

Where Vg and V_l represent the volumes of the gas and liquid phases respectively.

This value is influenced by several parameters including phase velocity, pressure, temperature and the nature of the carrier liquid. The electrical conductivity of the mixture varies greatly between phases, which allows this difference to be used to estimate gas retention.

The electrical conductivity of the two-phase mixture depends on the respective contributions of the phases. The measured electrical conductance Gmes can be approximated by an empirical law derived from the Maxwell-Garnett relationship (law of mixtures) often expressed in the form:

$$G_{mes} = G_l \times (1 - GVF) + G_g \times GVF \quad (2)$$

- G_l is the conductance of the liquid phase.
- G_g is the conductance of the gas phase (often negligible).
- GVF represents the gas volume fraction.

Since the conductance of the gas is generally very small compared to that of the liquid (Gg≈0), the equation often simplifies to:

$$G_{mes} = G_l \times (1 - GVF) \quad (3)$$

A. *Principle of conductance probes*

The principle of conductance probes is based on the measurement of the resistivity or conductivity of a fluid between two electrodes. Electrical conductivity varies significantly between the liquid and gas phases. The work of Jones and Zuber (1975) showed that the temporal and spatial resolution of the probes can be optimized by the choice of electrode configuration and sampling frequency. [52]

The advantage of integrated conductance probes is that they do not disturb the two-phase flow provided they are manufactured precisely. This is particularly important for annular flows where the liquid film is very thin. In this context, it is essential that the probe does not alter the waves on the surface of the film because even a slight disturbance could considerably distort the experimental results and introduce significant errors in the measurements. Different types of self-adaptive conductance probes have been developed to meet various applications. One of the first is the annular electrode probe consisting of two ring-shaped electrodes arranged

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around the circumference of the pipe and oriented perpendicular to the flow direction. This type of probe, capable of adjusting to variations in flow conditions, has been the subject of studies notably by Fossa [53] and Tsochatzidis et al. [54]. Additionally, four-electrode annular probes were used by Lina and Yingwei [55] to measure the water fraction in an annular two-phase oil-water flow where the oil flows in the center of the pipe and the water flows near the wall, forming a ring. These probes also allow the characterization of phenomena such as gas holdup in complex flows by providing accurate measurement of phase variations and dynamic behaviors of the fluid mixture.

Coney et al. [56] developed a two-electrode rectangular probe to measure the thickness of a corrugated film while minimizing flow disturbances. They also designed a three-electrode probe, segmenting the receiving electrode, to measure the ratio of currents between the sending electrode and the two receiving electrodes. This design corrects for the effects of temperature on conductivity and can be used to evaluate parameters such as film thickness and gas holdup in two-phase flows.

Lee et al. [57] used this three-electrode probe to determine film thickness under varying temperature conditions, demonstrating that the current ratio is insensitive to temperature-induced conductivity changes, which is essential for accurately characterizing gas holdup in unstable environments. In addition, Fossa et al. [53] performed measurements using two 3 mm diameter plate electrodes, arranged flush with each other with a separation of 9 mm in the axial direction of the pipe. Ko et al. [58] and Lee et al. [59] developed improved electrical conductance sensors for measuring gas holdup. Typically, a high-frequency alternating current (AC) is applied to the emitting electrode to avoid the formation of high ion gradients and redox electrochemical reactions that could damage the electrodes. The work by Ghendour et al. (2022) [60] focus on the optimization of conductance probes to measure gas holdup in two-phase flows, particularly in annular flows. The 2.2RE multi-electrode conductance probe developed by these authors measures gas holdup in gas-liquid two-phase flows by detecting conductivity variations between optimally arranged annular electrodes. Through numerical simulations and optimized design, the probe offers high sensitivity and accuracy with a linear relationship between output voltage and GVF. Experimental tests showed a low relative error compared to numerical data, thus providing a reliable method for measuring gas holdup in complex flows.

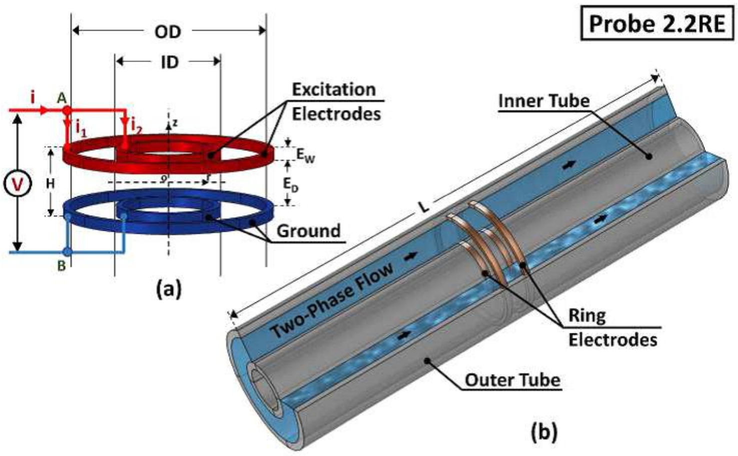

Fig. 2 Proposed probe 2.2RE: (a) schematic of the electrodes configuration and measurement strategy, (b) installation of the probe in the annulus channel. [60]

Conductance probes used for gas holdup measurement adjust their parameters (such as measurement frequency, electrode configuration, or conductivity threshold) to compensate for changes in conductivity caused by the varying presence of gas. This allows accurate measurements to be maintained even when the gas concentration changes rapidly, ensuring more reliable and responsive measurement under unstable operating conditions. These sensors can be integrated into industrial systems to monitor gas holdup in real-time in processes such as extraction, filtration, or multiphase flows.

B. *Factors Affecting the Measurement of Gas Retention by Conductance*

The accuracy of gas retention measurement by conductance depends on several key factors:

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- Excitation signal frequency: Using an alternating current (AC) signal is essential to avoid electrode polarization, a phenomenon that can distort measurements by creating a layer of charge on their surface. The signal frequency must be adapted to the conductivity of the solution: higher frequencies are generally used for high conductivities, while lower frequencies are preferable for low conductivities to minimize the influence of cable capacitance.

- Temperature and pressure: The electrical conductivity of fluids is strongly influenced by temperature. In general, an increase in temperature leads to an increase in conductivity due to increased ion mobility. Therefore, it is crucial to measure and compensate for temperature when making conductance measurements. Pressure can also affect the density and viscosity of the fluid, altering its conductivity, although this effect is generally less pronounced than that of temperature.

- Electrode configuration: The geometry of the electrodes, particularly their surface area (S) and the distance between them (L), directly influences the conductance measurement. The conductance (G) is proportional to the S/L ratio. An increase in the surface area of the electrodes or a decrease in the distance between them leads to an increase in the measured conductance. In addition, the arrangement of the electrodes affects the distribution of the electric field and therefore the measurement area. It is therefore essential to correctly calibrate the measuring cell, taking into account its cell constant, which depends on these geometric parameters.

IV. DESIGN OF THE GAS RETENTION MEASURING CHAIN

A. *Limitations of raw signals*

Advances in signal processing and automation have overcome traditional limitations of measurement systems, including nonlinearity and calibration dependency, particularly in applications such as gas holdup measurement. The integration of prediction models such as neural networks and adaptive filters can better handle nonlinearities and improve accuracy even under challenging conditions. These methods are essential for industrial environments such as the analysis of multiphase systems and transport pipes where measurement accuracy is crucial.

The work of Y. G. Lee (2017) demonstrated that advances in sensor technologies can overcome the limitations associated with calibration and nonlinearity of traditional measurements. This approach offers significant potential for improving the reliability of gas retention measurement systems under complex conditions. [61]

B. *Proposed gas retention measurement chain*

The proposed measurement chain uses multi-electrode probes arranged at different positions along the coaxial pipe allowing an accurate assessment of gas retention by capturing the spatial variations of this retention. These probes configured in coaxial mode measure the electrical resistance in the fluid thus providing data on gas retention in a gas-liquid mixture. They are connected to an electronic circuit designed to convert the conductance variation into a usable electrical signal while minimizing interference and ensuring reliable simultaneous measurements. The collected signals are then processed by a central unit such as a microcontroller or an FPGA which calculates the gas volume fractions. Analysis software allows real-time visualization of gas retention profiles with algorithms to filter the data and detect rapid fluctuations thus providing a detailed view of multiphase flows. Conductance probes by measuring the resistance between electrodes in the fluid play a vital role in this assessment, simultaneously capturing gas holdup variations at multiple strategic points along the coaxial tube for a complete analysis of the multiphase flow.

Each probe is connected to a dedicated electronic circuit that collects the measured data and transmits it for processing. These electronic circuits are grouped on a circuit board or in a central unit sometimes called a "control unit" that centralizes all the information coming from the probes. This unit is responsible for converting analog signals into digital data, managing interference, and performing real-time optimization

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using advanced algorithms. Optimization adjusts system parameters based on variations in flow conditions, ensuring accurate measurement in complex and unstable industrial environments.

The system architecture is modular in design, offering great flexibility in adding or removing probes according to specific needs. Dedicated software collects and analyzes data, providing real-time visualization of gas retention profiles. This modular system, with its ability to simultaneously measure multiple points and optimize parameters in real time, outperforms traditional systems. This hybrid approach offers increased flexibility and accuracy for multiphase flow analysis, perfectly adapting to the requirements of modern industrial environments.

V. DESIGN METHODOLOGY

A. *Modeling of conductance probes*

The modeling of conductance probes in two-phase flows is based on a thorough analysis of key parameters including the geometry of the coaxial tube, the distribution of the gas and liquid phases and the electrical properties of the fluids (conductivity and permittivity). These aspects directly influence the sensitivity, accuracy and robustness of the measurements. The probes are designed to meet the specific needs of two-phase flows using numerical simulation techniques to optimize their configuration and their spatial and temporal resolution.

To optimize the sensitivity of probes and their configuration in multiphase flows, several numerical approaches are used such as FEM and CFD simulations. These methods allow simulating the interaction between probes and fluids in order to define the optimal configuration of the probes while reducing errors due to interference. GHENDOUR et al (2022). [60]

Initial research, such as Tsochatzidis et al. (2002), shows that multi-electrode probes and their arrangement play a vital role in capturing local gas holdup variations with varied applications in the petroleum, chemical, and nuclear industries. Zhao et al. (2021) contributed to improving numerical models of probes to incorporate complex fluidic properties. Xiaoxiao Dong et al. (2017) developed an advanced conductance probe signal analysis approach focused on improving data accuracy and resolution under complex flow conditions. Abubakar et al. (2021) explored conductance measurement technologies in multiphase environments highlighting their applicability and challenges in using them under varied conditions. [62]- [65]

B. *Simulation of the gas retention measurement circuit*

The electronic chain integrating the probes is simulated using Proteus software. This approach allows validating the accuracy and speed of measurements under dynamic conditions while optimizing parameters such as the frequency and amplitude of the injected signals. Simulations are essential to reduce interference and ensure accurate conversion of electrical signals resulting from conductance variations. Shiwei Fan et al. (2014) demonstrated that optimizing the electronic circuit configuration can significantly improve the robustness and accuracy of measurement systems in complex gas-liquid flows. In addition, Ran Pang et al. (2024) highlight the importance of advanced simulation techniques to adjust sensor parameters and ensure their efficiency under diverse experimental conditions, particularly for multipoint measurements in multiphase systems. This work confirms the relevance of simulations to meet the increasing demands of modern industrial environments. [66], [67]

VI. AREAS OF APPLICATION

These conductance probes currently play a key role in various industrial applications such as pipeline monitoring and chemical reactor control to prevent blockages, and in chemical reactors to optimize heat and mass transfer, thus ensuring more efficient and safe management of industrial processes. The integration of this type of advanced circuitry improves system reliability in harsh environments.

VII. CONCLUSIONS AND PERSPECTIVES

This literature review highlights the potential of conductance probes to improve gas retention measurement in two-phase flows. By combining these probes with optimized electronic circuits, the proposed approach

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overcomes the limitations of traditional methods, offering greater accuracy, increased robustness, and adaptability to dynamic flow conditions. These advances open up promising prospects for industrial applications, with future research focused on the development of operational sensors and electronic circuit optimization.

In the short term, future work will focus on the design and implementation of an operational conductance sensor to measure gas retention along a coaxial tube. These measurements will validate the sensor's performance and analyze two-phase flow regimes. Subsequently, optimization of the conditioning circuit will be considered, accompanied by the development of a real-time measurement chain for more precise analysis adaptable to industrial environments.

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ISSN: 1737-9334