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### Sensor element for detecting and locating soft drink leaks in bottling plant pipelines

### Elemento sensor para detección y localización de fugas de refrescos en tuberías de instalaciones embotelladoras

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**Technological innovation:** To detect leaks in real time with distance location.

**Industrial application area:** Carbonated beverage bottling industry.

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### Resumen

En la industria de refrescos embotellados es común la utilización de tuberías, sin embargo, las fugas no detectadas pueden provocar pérdidas o daños en las instalaciones; por lo cual el objetivo de esta investigación es proponer un elemento sensor que permita detectar fuga y localizar su ubicación exacta lo más rápido posible. Se desarrolló un sensor tipo cable formado por copolímeros y alambres de nicromo para detectar fugas de refrescos carbonatados en tuberías de proceso, el copolímero se sintetizó con poli(n-acrilato de butilo) al 70% y poli(ácido acrílico) al 30% mediante polimerización en emulsión radical, los ingredientes se colocan juntos en un matraz de dos bocas, se adiciona nitrógeno mediante burbujeo luego se fijan a 60 °C a 70 °C con agitación para iniciar la polimerización. El prototipo de cable tiene dos alambres embebidos de nicrom que constituyen un sistema de detección eléctrica que utiliza la conductividad del agua del refresco para la detección y localización de fugas con alta precisión (niveles de error de +/- 0.0002% en los primeros 3 minutos). La humedad del ambiente no afecta la sensibilidad del sensor.

**Palabras clave:** Bebidas carbonatadas, Fugas, Polímero, Sensores.

## Abstract

In the bottled soft drink industry, the use of pipelines is common; however, undetected leaks can lead to product loss or damage to the facilities. Therefore, the objective of this research is to propose a sensor element capable of detecting leaks and pinpointing their exact location as quickly as possible. A cable-type sensor was developed, composed of copolymers and nichrome wires, designed to detect leaks of carbonated soft drinks in processing pipelines. The copolymer was synthesized using 70% poly (n-butyl acrylate) and 30% poly (acrylic acid) through radical emulsion polymerization. The ingredients were combined in a two-neck flask, nitrogen was introduced via bubbling, and the reaction mixture was maintained at 60–70 °C under stirring to initiate polymerization. The cable prototype features two embedded nichrome wires that form an electrical detection system, utilizing the conductivity of the beverage's water content to detect and locate leaks with high precision (error margins of  $\pm 0.0002\%$  within the first 3 minutes). Ambient humidity does not affect the sensor's sensitivity.

**Keywords:** Leak Detection, Carbonated Beverages, Copolymers, Sensor Systems, Pipeline Monitoring.

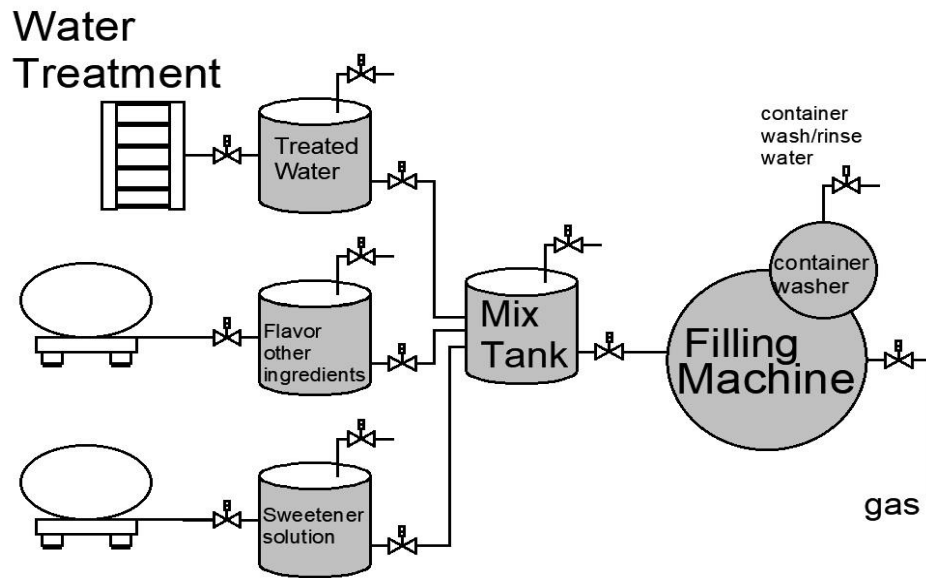
## 1. Introduction

Carbonated soft drinks are among the most highly consumed beverages globally, primarily manufactured by PepsiCo, Coca-Cola, and Dr. Pepper Snapple. These beverages contain artificial or natural sweeteners, vitamins, caffeine, fruit extracts, preservatives, and flavoring agents; the market size was worth USD 221.6 billion in 2020, with consumption projected to rise due to population growth and greater product accessibility ([www.Grandviewresearch.com](http://www.Grandviewresearch.com)).

The first carbonated beverage was produced in Geneva during the eighteenth century. Soft drinks typically have fruity, spicy, or herbaceous flavors, such as those found in cola drinks. Manufacturing is carried out

using two basic methods: the premix and postmix systems; in the first, all ingredients are blended before the final volume is chilled and carbonated; in the second (Figure 1), a concentrated syrup containing all ingredients except the majority of water and carbon dioxide is prepared. The syrup is then pasteurized and diluted. Water for dilution is chilled and carbonated separately. The two components are blended in the required amounts, and the carbonated product is then fed into the filler (Ashurst, 2016).

Each of these stages relies heavily on pipelines and storage systems, which increases the potential for undetected leaks. A distributed sensor can be placed along the length of the pipe and used to detect the leak and its location.



**Figure 1.** Soft drink *postmix* production diagram [own creation].

Such leaks pose a significant economic risk to large manufacturers. Due to the high volume handled, it is necessary to detect leaks with accuracy and speed. New technologies for leak detection include sensor innovations like Oxidation Potential Sensors for leak detection in water distribution, Pressure Sensors, Sensor Nodes for detection in plastic pipes, Acoustic Sensors, and Transducer Gem's Sensor 2000 for leak detection in zigzag pipelines (Neeraj et al., 2017). Detecting the leak is just as important as locating the leak site. Some researchers have focused on developing new methods to pinpoint the exact location of leaks; Casillas et al. (2015) presented a model-based optimization method for near-optimal sensor placement to detect leak nodes in water distribution networks using pressure sensors; they termed this the Leak Signature Space (LSS). Jia et al. (2014) presented a hoop strain-based Negative Pressure Wave (NPW) method to detect and localize leakages in PVC pipelines. In general, leak detection techniques are based on measuring specific phenomena or physical quantities such as acoustic signals, pressure, flow rate, vapor sampling, fiber optics, and cable sensors.

Regarding cable sensors, Oh et al. (2018) published an acoustic-based leak detector that detects associated changes in pressure and flow when a pipe experiences a sudden rupture or crack, which enables identification of the leak location between two measured points. When a cable sensor is used for leak detection, it can be integrated into the same structure as the cable itself. Cheng et al. (2017) developed a coaxial cable consisting of an inner conductor, an outer conductor, and a dielectric layer.

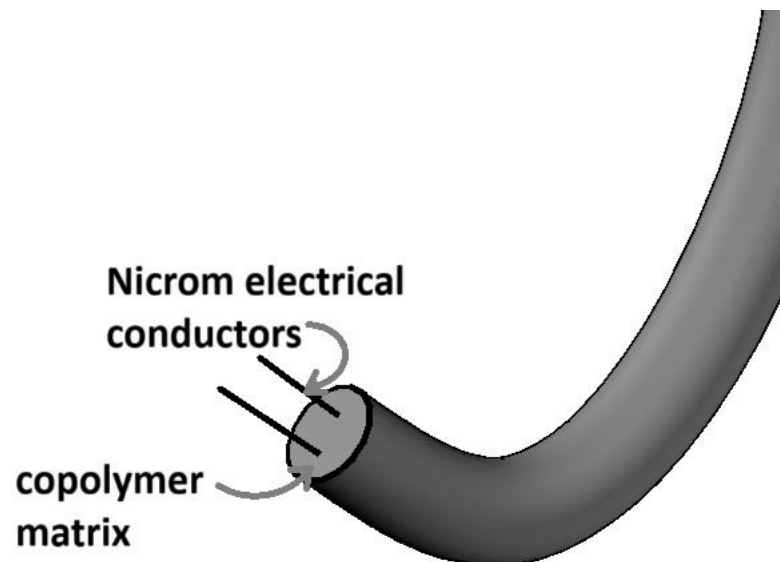
The use of polymers for detecting physicochemical changes has been widely reported. Penza et al. (2001) used a rubbery polymer as a sensitive membrane for gas and humidity detection. The polymer's response to physical changes is crucial for its intended application, where high sensitivity, repeatability, and linearity are desirable. Today, the use of sensors has been increasingly combined with IoT-based systems for monitoring liquid leaks in infrastructure (Ahmed et al., 2023).

This study presents a cable sensor specifically designed to detect leakages of carbonated soft

drinks. The cable sensor is designed to be placed alongside processing pipelines. Its sensitivity allows it to detect leaks as small as a centiliter per minute, which would otherwise go unnoticed visually or through mass balance. Its response time is very fast—within just a few seconds, the leak is detected and significant product loss is avoided. In previous work, a distributed sensor for aqueous solutions was presented (Mendoza-Payán et al., 2009), using crosslinked polyvinyl amine with Cu(II); that sensor had an ultra-fast response. With the same approach, the current cable sensor was developed using a polymer material synthesized from acrylic acid and butyl

acrylate. The resulting copolymer has notable properties: it can be extruded to form a cable, is flexible enough to handle, and firm enough to house two Nichrome (an alloy of nickel and chromium) wires at its core.

Figure 2 shows the cable sensor formed by the synthesized polymer and two Nichrome wires. It is highly sensitive to the presence of water but not to ambient humidity, thus avoiding false alarms. The length of the cable sensor can be adjusted as needed. The sensor was designed to detect and localize leaks of carbonated soft drinks, and is intended to be distributed along process pipelines.



**Figure 2.** Cable sensor featured.

The cable sensor operates as a resistive sensor. A voltage is applied to a closed-circuit configuration, and when a leak occurs, a variation in resistance is detected. These variations enable the calculation of the leak's location using Eq. (1). Figure 3 illustrates the system, where two loops of Nichrome wire

form a closed circuit. At each end, 24 VRMS (Root Mean Square Voltage) is applied.

When the system is initiated, the polymer resistance ( $R_{pol}$ ) is very high, resulting in a very low current. Current values are acquired by an A/D data card at a sampling frequency

of 24 data points per minute, by measuring the voltage drop across a pair of precision resistors (22 ohms, ±1% accuracy).

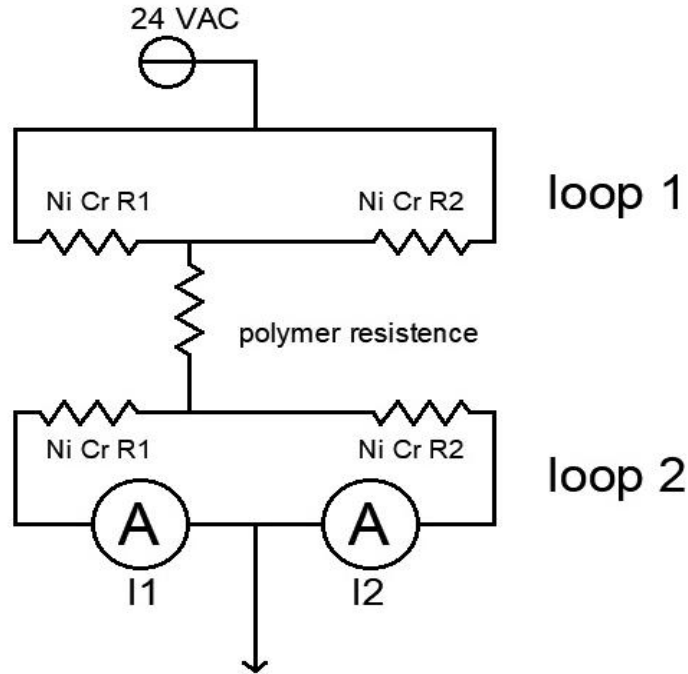


Figure 3. Resistive circuit system for cable sensor.

$$L_C = (I_2 * L_T) / (I_1 + I_2) \dots\dots\dots(\text{Eq. 1})$$

Where:

$L_C$  sensor length in which the leak is presented

$L_T$  total length of the sensor

$I_1$  loop 1 intensity value

$I_2$  loop 2 intensity value.

**2. Experimental**

**2.1. Materials and equipment**

Monomers poly(acrylic acid) (> 98%), poly(n-butyl acrylate) (> 98%), by Aldrich

were purified before use, the purification process involved 80 °C vacuum distillation. The initiators supplied by Sigma-Aldrich: potassium persulfate (> 99%) and ammonium persulfate (> 99%) were purified by rechristening and dried at 35 °C in vacuum. The surfactants: polyvinyl alcohol (> 80% hydrolysis, JT Baker), sodium lauryl sulfate (> 99%, JT Baker), and Triton X-305 (70% solution w / w, JT-Baker) were used without treatment. A data acquisition card from National Instruments® with 14-bit resolution and a sampling rate of 48 kS/s was used to collect data. The LabView® diagram is shown in Figure 4.



The extrusion process was carried out using a Brabender© plasticorder with Banbury blades. Polyethylene glycol was used as an internal lubricant and plasticizer to enhance material integration, in the process a mixing was realized during 10 minutes using 2% plasticizer/copolymer ratio in mass.

The cable sensor extrusion was performed in a Brabender© with die coater cable, this equipment allows inserting a Nichrome wire core. Table 1 shows the extrusion conditions for line production.

**Table 1.** Extrusion conditions for line production.

Parameter	Value	Unit
Feed temperature	65	°C
Plasticizing temperature	70	°C
Compression temperature	75	°C
Dosage temperature	80	°C
spindle speed	3	RPM
spindle L/D	20	Dimensionless
spindle torch	7.2	N.m

### 2.3. Experimental methodology

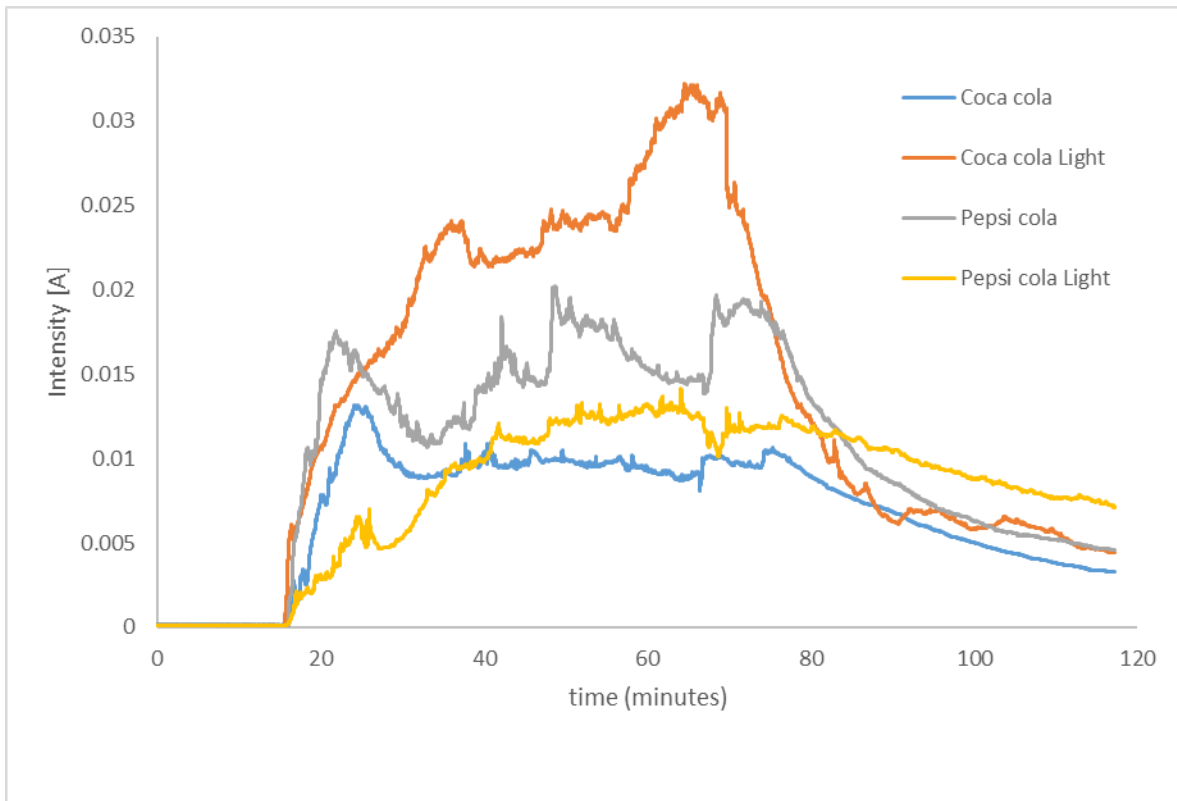
At the beginning of the experiment, the system was operated without the presence of liquids for 16 minutes to establish baseline data. After this period, a small section of the cable sensor (2 centimeters) was immersed in a carbonated soft drink to simulate a leak.

Four carbonated soft drinks were used in the experiment: Coca-Cola, Coca-Cola Light, Pepsi, and Pepsi Light, all in 255 mL presentations. The simulated leak condition lasted for 50 minutes, after which the cable sensor was removed from the soft drink and subjected to a desorption phase for another 50 minutes. The ambient temperature fluctuated between 23 °C and 25 °C.

### 3. Results

Figure 6 shows the intensity behavior in loop 2 of the cable sensor circuit exposed to carbonated soft drink samples during the simulated leak. The four beverages used were Coca-Cola, Coca-Cola Light, Pepsi, and Pepsi Light, all in 255 mL presentations. The experiments were conducted at 25 °C and 43% relative humidity (RH).

During the initial 16 minutes, the polymer's resistance was very high, resulting in a very low intensity reading (0.00015 Amperes). Once the cable sensor was exposed to the beverage, it formed a conductive bridge, causing the intensity to increase immediately to approximately 0.001 Amperes. The intensity value continued to increase over time.



**Figure 6.** Sensor typical intensity response in a soft drink leak situation.

The highest intensity value was recorded for Coca-Cola Light, reaching 0.03 Amperes. The second-highest value was for Pepsi, which showed a very similar response to Coca-Cola, both around 0.013 Amperes. The lowest value was for Pepsi Light, at approximately 0.01 Amperes. As shown, the values fluctuated slightly but consistently increased for all four beverages.

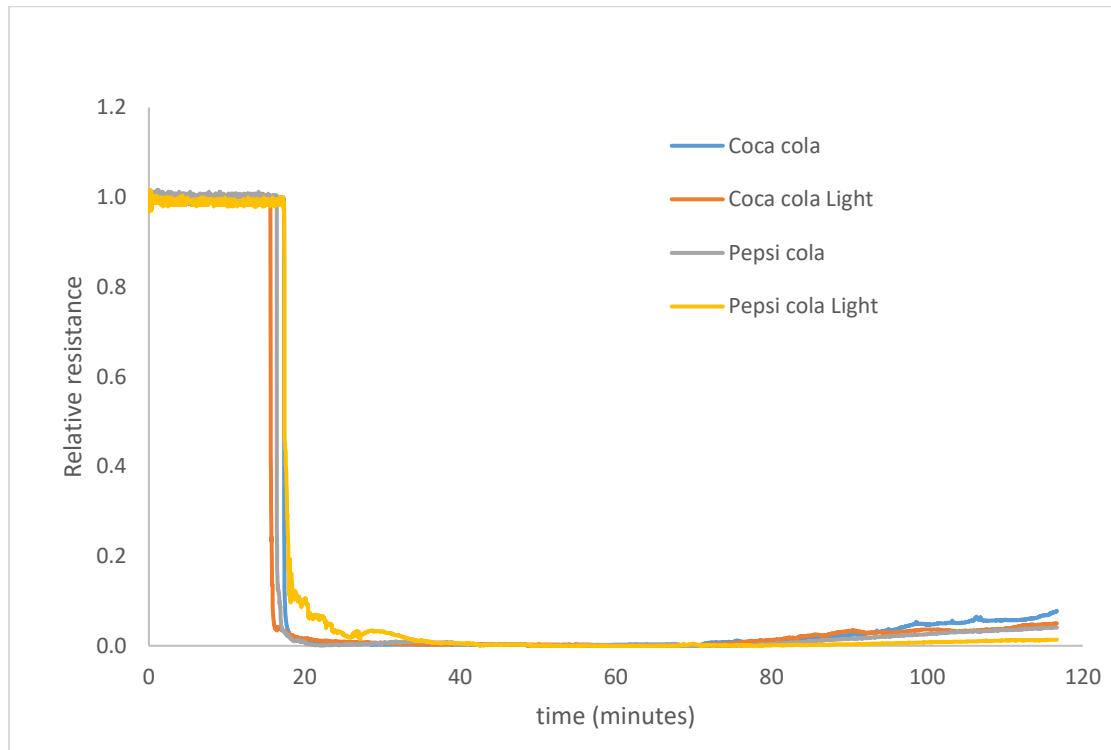
After 50 minutes, the cable sensor was removed from the soft drink. During the desorption phase, a distinct pattern was observed: initially, the remaining liquid caused some fluctuations around the last recorded intensity value, but after a few minutes, a clear desorption behavior emerged.

Rapid detection is essential in leak events to minimize product loss. Other systems can take several seconds or even minutes to detect a leak. For example, Zhang et al. (2018)

presented a particle swarm optimization-based method that requires upstream and downstream pressure data and takes almost 60 seconds to determine the existence and location of a leak. Fahim et al. (2017) introduced a surface acoustic wave (SAW) sensor system that also needs several seconds to collect and process data. Our system, by contrast, detected the leak within a few seconds and determined the location with minimal error in under one minute. However, it does not measure the intensity or volume of the leak, unlike other methods based on flow rate discrepancies between the inlet and outlet (Romero-Ben et al., 2023; Wan et al., 2022).

As demonstrated, polymer properties play a crucial role in sensor performance. The ratio of monomers significantly influences the copolymer's properties. The high butyl acrylate concentration (70%) in the synthesis process provides flexibility and enhances the adsorption-desorption characteristics

(Kitayama et al., 2011), while the 30% acrylic acid content contributes to polymer cohesion (Zhou et al., 2014).



**Figure 7.** Sensor typical resistance response in a soft drink leak situation.

Figure 7 illustrates the resistance response of the sensor to a soft drink leak. Three distinct phases are clearly visible: the first 16 minutes of baseline data acquisition, followed by a 50-minute drop in resistance in response to liquid exposure (from minute 16 to 66), and finally, the desorption phase.

Considering that Nichrome has a resistance of 13.69 Ohms per meter, the accuracy of the leak location improves as the current is increased at both sensor ends. This is because

increased signal strength outweighs the effect of noise, a result of enhanced electrolyte conductivity as the polymer swells. This behavior is shown in Figure 8, which plots leak location distances for each beverage: Coca-Cola at 194 cm, Coca-Cola Light at 176 cm, Pepsi at 184 cm, and Pepsi Light at 181 cm. Cardell-Oliver (2015) used triangulation and time-of-arrival methods across sensor networks to locate leaks, but this method did not achieve the same level of precision in leak localization.

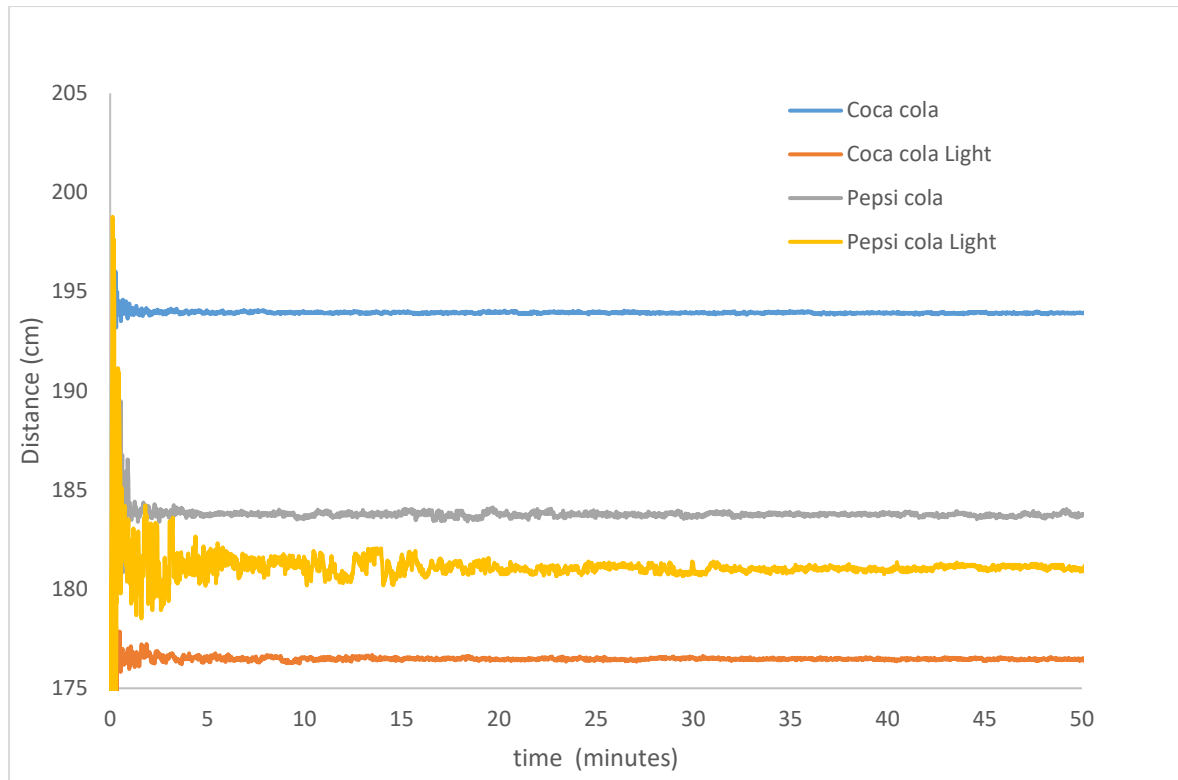


Figure 8. System development for leak localization.

Table 2 shows how the percentage error decreased across all beverage samples during the first five minutes of contact with the sensor. Figure 9 displays the relative error in

leak location over time for the Coca-Cola sample, demonstrating that accuracy improves as more time elapses.

Table 2. Relative error development for all beverage’s assays.

Product	30 seconds	1 min	2 min	3 min	4 min	5 min
Coca cola	1.003	1.002	1.001	1.0005	1.0004	1.00008
Coca cola Light	1.007	1.003	1.001	1.001	1.0002	1.0006
Pepsi cola	1.01	1.002	1.002	1.001	1.0001	1.0001
Pepsi cola Light	1.013	1.008	1.008	1.002	1.001	1.001

The sensor operates based on the short circuit formed between both conductors due to the diffusion of beverage fractions into the polymer material. It is important to evaluate how conductivity behaves in relation to °Brix. Figure 10 illustrates the results of the conductivity analysis performed on Coca-Cola and Pepsi samples. Conductivity was measured using a Thermo Scientific Orion VersaStar Advanced Electrochemistry Meter, and °Brix was measured using an ABBE Refractometer (Atago® Model NAR\_2T).

It was observed that as water evaporated, the °Brix value increased, and conductivity rose, thereby enhancing the sensor’s performance. For Coca-Cola, the °Brix started at 7.48 and increased to 33.4, while conductivity also rose as water evaporated from the sample. Pepsi initially presented a °Brix of 7.48, increasing to 22.45, and similarly showed an increase in conductivity. This behavior facilitates the formation of a short circuit

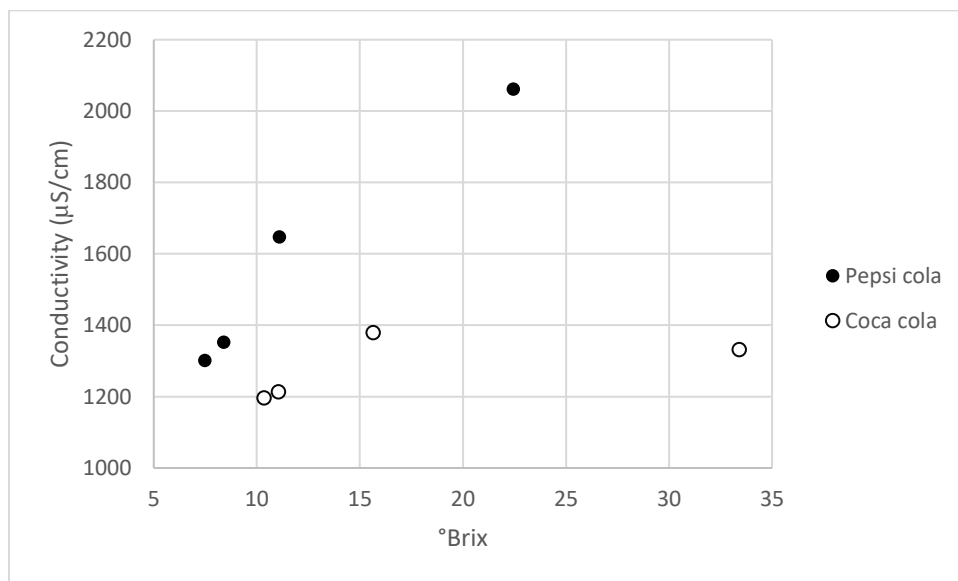
between the two sensor loops, which is essential for leak localization.

From Figures 6, 7, and 8, we can deduce the sensor's behavior during the initial 16 minutes of operation without a leak. During this time, current levels were low due to the high resistance of the polymer, which introduces two notable system features. The first is a detection threshold a minimum current level that must be exceeded to confirm the presence of a leak. When the current surpasses this threshold, the system initiates leak location calculations. Wu et al. (2017) designed a leak sensor that had to physically move inside the pipe to reach the leak point and required constant fluid velocity. Our system, in contrast, is stationary and does not rely on movement.

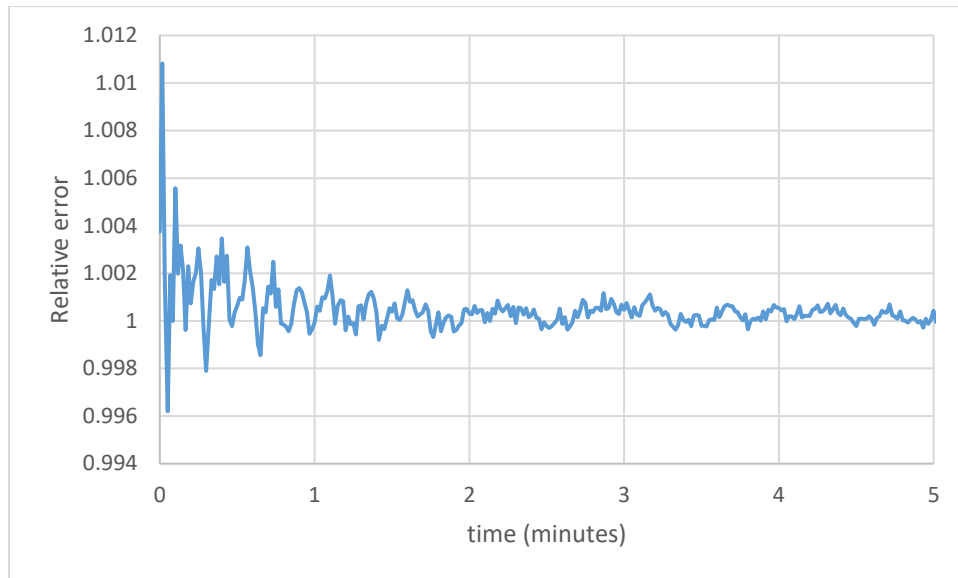
The second feature relates to energy efficiency. In its dry state, the sensor

consumes very little power—approximately 0.4 mA. After the first 16 minutes, the subsequent stage marks the sensor's response time. Within a few seconds of contact between the sensor and the soft drink, the current rises to levels sufficient to determine the leak location with high precision.

The final stage involves the desorption phase, which shows a gradual recovery due to the need for mass diffusion from the sensor core to the surface. Additionally, the evaporation of liquid is slowed by the sugar concentration that forms on the polymer surface, as the polymer acts as a medium for water removal. This results in a shallow desorption slope, requiring several hours for the sensor to return to its original dry-state performance. The diffusion coefficient of soft drinks is approximately  $10^{-12}$  m<sup>2</sup>/s and is strongly temperature-dependent (Salas et al., 2018).



**Figure 10.** Conductivity analysis of soft drink accord to °Brix.



**Figure 9.** Relative error for leak location when a Coca cola leak was simulated.

Wu et al. (2017) developed sensors that needed to travel at 0.4 m/s to locate a leak. If the flow rate varied, their location calculation became inaccurate (Katalin, 2006). Regarding localization, the current levels across the channels must reach the detection threshold within one minute of contact with the liquid. Beyond this time, the leak localization error remains extremely low—within  $\pm 0.001\%$ . Jia et al. (2014) used a hoop strain system to locate leaks with an average error of 7.33%, while Luo et al. (2011) reported a location error between 10% and 30% and required an additional correction value of 0.22.

### Conclusions

The sensor system presented in this study demonstrates the capability to detect and localize leaks or micro-leaks in soft drink pipeline systems with high accuracy ( $\pm 0.002\%$  within 3 minutes). Another notable feature is the sensor's reusability—it only requires a recovery period (desorption step) before being operational again. The system is also highly safe, operating at low voltage and current levels, which eliminates any risk of electrocution.

### References

- Ahmed, S., Mouël, F. L., Stouls, N., & Kouyi, G. L. 2023.** Development and Analysis of a Distributed Leak Detection and Localisation System for Crude Oil Pipelines. *Sensors*, 23(9), 4298. <https://doi.org/10.3390/s23094298>
- A. Katalin. 2006.** "Data Acquisition for Pressure Monitoring and Control in Distributed Systems," IEEE International Conference on Automation, Quality and Testing, Robotics, Cluj-Napoca, Romania, 2006, pp. 157-160, doi: 10.1109/AQTR.2006.254622.
- Ashurst, P. R. 2016.** Carbonated beverages. In *Elsevier eBooks*. <https://doi.org/10.1016/b978-0-08-100596-5.03240-6>
- Casillas, M. V., Garza-Castañón, L. E., & Puig, V. 2015.** Sensor placement for leak location in water distribution networks using the Leak signature space. *IFAC-PapersOnLine*, 48(21), 214–219. <https://doi.org/10.1016/j.ifacol.2015.09.530>

**Cheng, B., Yuan, L., Zhu, W., Song, Y., & Xiao, H. 2017.** A coaxial cable magnetic field sensor based on ferrofluid filled Fabry-Perot interferometer structure. *Sensors and Actuators A: Physical*, 257, 194–197. <https://doi.org/10.1016/j.sna.2017.02.024>

**Fahim, Mainuddin, U. Mittal, J. Kumar, A. T. Nimal and M. U. Sharma. 2017.** "Single chip readout electronics for SAW based gas sensor systems," IEEE SENSORS, Glasgow, UK, 2017, pp. 1-3, <https://doi.org/10.1109/ICSENS.2017.8233886>.

Grand View Research GVR-2-68038-144-3 consulted 30 april 2024. <https://www.grandviewresearch.com/industry-analysis/carbonated-soft-drinks-market>

**Jia, Z., Ren, L., Li, H., Ho, S., & Song, G. 2014.** Experimental study of pipeline leak detection based on hoop strain measurement. *Structural Control & Health Monitoring*, 22(5), 799–812. <https://doi.org/10.1002/stc.1718>

**Kitayama, Y., Moribe, H., Minami, H., & Okubo, M. 2011.** Emulsifier-free, organotellurium-mediated living radical emulsion polymerization of Styrene: Initial stage of polymerization. *Polymer*, 52(13), 2729–2734. <https://doi.org/10.1016/j.polymer.2011.04.027>

**K. Luo, A. Shui, S. Li, Z. Li and J. Chen. 2011.** "Sensor cable-based tank leak detection system," Chinese Control and Decision Conference (CCDC), Mianyang, China, 2011, pp. 1320-1324, doi: 10.1109/CCDC.2011.5968394.

**Salas M., Martina Hubner, Mykhailo Borisov, Michael Koerdt, Marcel Rennoch, Axel S. Herrmann, Walter Lang. 2018.** "Measuring Material Moisture in Fiber Reinforced Polymers by Integrated Sensors,"

in *IEEE Sensors Journal*, vol. 18, no. 9, pp. 3836-3843, 1 May 2018. doi: 10.1109/JSEN.2018.2815029.

**Mendoza-Payán, J. G., Gallardo, S. F., & Márquez-Lucero, A. 2009.** Design for an ultrafast water distributed sensor employing polyvinylamine cross-linked with Cu(II). *Sensors and Actuators B: Chemical*, 142(1), 130–140. <https://doi.org/10.1016/j.snb.2009.07.045>

**Neeraj, P. K. Suri and V. Yadav. 2017.** "Design and implementation of wireless sensor network architecture for leak detection and monitoring in water supply distribution network" 2nd International Conference for Convergence in Technology (I2CT), Mumbai, India, 2017, pp. 559-564, doi: 10.1109/I2CT.2017.8226192.

**Oh, S. W., Yoon, D., Kim, G. J., Bae, J., & Kim, H. S. 2018.** Acoustic data condensation to enhance pipeline leak detection. *Nuclear Engineering and Design*, 327, 198–211. <https://doi.org/10.1016/j.nucengdes.2017.12.006>

**Olivier Colombani, Markus Ruppel, Frank Schubert, Heiko Zettl, Dmitry V. Pergushov, and Axel H. E. Müller. 2007.** Synthesis of Poly(n-butyl acrylate)-block-poly(acrylic acid) Diblock Copolymers by ATRP and Their Micellization in Water. *Macromolecules*. 40(12). 4338–4350. [doi.org/10.1021/ma060957815](https://doi.org/10.1021/ma060957815)

**Penza, M., Cassano, G., Sergi, A., Lo Sterzo, C., & Russo, M. V. 2001.** SAW chemical sensing using poly-ynes and organometallic polymer films. *Sensors and Actuators B: Chemical*, 81(1), 88–98. [https://doi.org/10.1016/s0925-4005\(01\)00937-6](https://doi.org/10.1016/s0925-4005(01)00937-6)

**Cardell-Oliver, R., Scott, V., Chapman, T., Morgan, J., & Simpson, A. 2015.** Designing

sensor networks for leak detection in water pipeline systems," IEEE Tenth International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP), Singapore. 1-6, doi: 10.1109/ISSNIP.2015.7106909.

**Romero-Ben, L., Alves, D., Blesa, J., Cembrano, G., Puig, V., & Duviella, E. 2023.** Leak detection and localization in water distribution networks: Review and perspective. *Annual Reviews In Control*, 55, 392-419.  
<https://doi.org/10.1016/j.arcontrol.2023.03.012>

**Salas, M., Hubner, M., Borysov, M., Koerdt, M., Rennoch, M., Herrmann, A. S., & Lang, W. 2018.** Measuring Material Moisture in Fiber Reinforced Polymers by Integrated Sensors. *IEEE Sensors Journal*, 18(9), 3836-3843.  
<https://doi.org/10.1109/jsen.2018.2815029>

**Wu, Y., Kim, K., Henry, M. F., & Youcef-Toumi, K. 2017.** "Design of a leak sensor for operating water pipe systems," IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Vancouver, BC, Canada, 2017, pp. 6075-6082, doi:10.1109/IROS.2017.8206506.

**Wan, X., Kuhanestani, P. K., Farmani, R., & Keedwell, E. 2022.** Literature Review of Data Analytics for Leak Detection in Water Distribution Networks: A Focus on Pressure and Flow Smart Sensors. *Journal Of Water Resources Planning And Management*, 148(10).  
[https://doi.org/10.1061/\(asce\)wr.1943-5452.0001597](https://doi.org/10.1061/(asce)wr.1943-5452.0001597)

**Zhang, H., Zhang, W., Xu, N., Guo, Z., & Wu, G. 2018.** Improved PSO-based method for leak detection and localization in liquid pipelines. *IEEE Transactions on Industrial*

*Informatics*, 1.  
<https://doi.org/10.1109/tii.2018.2794987>

**Zhou, J., Wang, H., Zhang, L., & Ma, J. 2014.** Ab initio reversible addition-fragmentation chain transfer emulsion polymerization of styrene/butyl acrylate mediated by poly(acrylic acid)-block-polystyrene trithiocarbonate. *Polymer International*, 63(12), 2098-2104.  
<https://doi.org/10.1002/pi.4755>