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Hydrocarbon inventory system. Solutions with Endress+Hauser

Sistema de inventario de hidrocarburos. Soluciones con Endress+Hauser

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Abstract

This article presents a technological solution for the automated management of hydrocarbon inventories in storage tanks, focusing on the integration of high-precision sensors, volumetric correction algorithms, and a modular architecture based on international standards such as API MPMS, ISO 13879, and OIML R85. The Tankvision system, an IoT platform that enables real-time monitoring, metrological traceability, and regulatory compliance, is highlighted. In addition, operational advantages, safety, and possible future developments such as the use of blockchain and digital twins are analyzed.

Keywords: Modular architecture, Automated inventory management, Hydrocarbons, High-precision sensors, Tankvision

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Resumen

Este artículo presenta una solución tecnológica para la gestión automatizada de inventarios de hidrocarburos en tanques de almacenamiento, enfocándose en la integración de sensores de alta precisión, algoritmos de corrección volumétrica y una arquitectura modular basada en estándares internacionales como API MPMS, ISO 13879 y OIML R85. Se destaca el sistema Tankvision, una plataforma IoT que permite monitoreo en tiempo real, trazabilidad metrológica y cumplimiento normativo. Además, se analizan ventajas operativas, seguridad y posibles líneas futuras como el uso de blockchain y gemelos digitales.

Palabras clave: Arquitectura modular, Gestión automatizada de inventarios, Hidrocarburos, Sensores de alta precisión, Tankvision.

1. Introduction

Companies that produce or market high volumes of fossil fuels require real-time inventory systems that ensure accurate management of their liquid assets [1]. Given that these inventories represent a significant percentage of the companies' equity value, their measurement must comply with international standards that ensure accuracy in the calculation of volumetric and mass variables [2].

To this end, control systems must meet key regulatory requirements: measurement accuracy between 4 and 6 mm in level, standardized volumetric correction algorithms, and the ability to generate various reports. In particular, level measurement in tanks is critical, not only for the balance of raw materials and finished products, but also for the efficient operation of the process.

A significant technical challenge is the presence of multiple interfaces (air-fuel and fuel-water with sediments), which requires specialized instrumentation that offers a better cost-benefit ratio [3]. The selection of equipment must consider both the characteristics of the fluid and the specific operating parameters of each facility [4].

Hydrocarbon inventories must ensure compliance with accuracy and reporting requirements [5]. To do this, complex fluid interfaces must be handled correctly with technological solutions. The objective of this article is to evaluate state-of-the-art automation infrastructure to achieve safe, accurate, and optimized operations in real-time hydrocarbon tank inventory with Endress+Hauser technology (Tankvision).

The research was based on the dialectical materialist conception of scientific knowledge, from which an answer to the research problem is sought. Scientific research methods were applied at the theoretical and empirical levels of knowledge. At the theoretical level, the analytical-synthetic method was applied, which allowed the core concepts of the system to be broken down for analysis of their particularities. The inductive-deductive method favored reaching generalizations about the characteristics of the methodology's development. At the empirical level, a review of documents was applied to contrast the methodologies, their similarities, and differences in the implementation of the systems.

2. Mathematical modeling for hydrocarbon inventory

Reliable quantification of hydrocarbon inventories in storage tanks requires a standardized approach that integrates critical variables such as temperature, density, and tank geometry. This process, based on international standards such as the Petroleum Measurement Standards Manual [4] and ASTM Guide D1250-22 [6], follows a rigorous methodology to ensure accuracy and metrological traceability.

2.1. Fundamental corrections

The net volume (Vnet) is obtained by adjusting the gross volume (Vgross) using thermal correction factors (CTL) and sedimentation correction factors (CSW), according to equation (1).

$$Vnet = Vgross \times CTL \times CSW \quad (1)$$

The CTL considers the thermal expansion coefficient of the hydrocarbon (typically between 0.0008 and 0.0009 $°C^{-1}$ for crude oil and diesel) and the deviation from the standard temperature (15°C or 60°F).

2.1.1. Data sources and accuracy

The gross volume is derived from tank-specific calibration tables based on level measurements (h). In cases where water and sediment are present (BS&W > 0%), an additional factor is applied to exclude impurities from the net volume.

Recent studies [7] highlight that the use of LSTM neural networks with multipoint RTD sensor data improves accuracy in stratified thermal profiles (±0.05°C), surpassing conventional methods.

2.1.2. Automation and regulatory compliance

The implementation of these calculations in SCADA systems allows for: Real-time corrections, automatic generation of reports under standards (API MPMS Chapters 3, 7, 9), and auditable traceability for fiscal and logistical applications.

This approach not only minimizes errors associated with thermal variations or contamination, but also optimizes inventory management by aligning with international best practices (OIML R85) [8]. The integration of advanced technologies, such as artificial intelligence and high-precision sensors, reflects the evolution towards more scientific and efficient management of petroleum assets.

3. SCADA systems for automated hydrocarbon inventory management in storage tanks

Supervisory control and data acquisition (SCADA) systems have revolutionized hydrocarbon inventory management by integrating advanced measurement and control technologies. This technological solution allows oil companies to monitor their assets with greater precision, efficiency, and security, transforming traditional operational processes [9].

3.1. Essential system components

3.1.1. Liquid level measurement

The system uses complementary technologies to ensure accuracy under various operating conditions: Guided wave radar (TDR), which stands out for its millimeter precision (±1 mm) and resistance to adverse conditions such as vapors or foam formation; servo-gauges that offer maximum accuracy (±0.5 mm) for fiscal and custody transfer applications; and ultrasonic sensors applicable in specific cases with non-flammable products.

3.1.2. Monitoring of critical variables

Critical variable monitoring includes: Thermal profiles using multi-point RTDs (Pt100); continuous density measurement using Coriolis technology densimeters; and automatic water and sediment detection (BS&W).

3.1.3. Communications infrastructure

Communications infrastructure is important in inventory systems. It consists of: a network of smart transmitters with industrial protocols (HART, Fieldbus); PLC/RTU controllers ( ) for distributed processing; and standardized communications gateways (OPC UA, Modbus TCP).

3.1.4. Integrated safety modules

Integrated safety modules consist of: Overfill prevention systems; Leak detectors with differential pressure sensors and electronic seals for access control.

The implementation of these systems provides significant operational advantages, including: Metrological accuracy that surpasses conventional manual procedures, immediate response capability to operational incidents; automatic generation of regulatory reports (API MPMS, ISO 4266) and synergistic integration with enterprise resource planning (ERP) systems.

This technological solution represents a substantial advance in storage asset management, enabling: Optimization of operational and human resources; reduction of environmental and operational risks; continuous improvement of processes through historical data analysis and automated compliance with international regulations.

The evolution towards automated inventory management systems reflects the digital transformation of the oil industry, where accuracy, safety, and operational efficiency have become fundamental pillars for business competitiveness [10].

4. Theoretical basis for the integration of Tankvision's modular and distributed architecture

4.1. Theoretical basis of the Tankvision inventory system

Several authors have provided the theoretical basis for the Tankvision inventory system. These theoretical foundations are key to the analysis of this research.

Other authors propose a theoretical framework for modeling hierarchical embedded systems using hybrid automata (a combination of discrete and continuous components) [11]. In addition, they introduce formal methods for analyzing real-time properties, stability, and fault tolerance in complex systems. This allows for decentralized control where each module (e.g., custody-transfer approval per NMi and PTB standards NXA820) operates autonomously but cooperates to achieve the overall objective (accurate inventory).

This operation ensures real-time feedback with sensors that adjust measurements through feedback loops (e.g., continuous thermal correction).

Parnas [12], proposes criteria for the modularization of software systems, emphasizing the principle of information hiding. This is a key contribution to modular architecture, which should minimize coupling between components to facilitate maintenance and scalability. This support is relevant to the Tankvision system because it justifies the modular design of the custody-transfer approval per NMi and PTB standards custody-transfer approval per NMi and PTB standards NXA820- NXA822 components, which operate independently but in an integrated manner.

Saridis [13] presents his theory of hierarchical control in stochastic systems, with three levels: organization, coordination, and execution. This allows tasks to be assigned to different levels according to complexity (e.g., SCADA vs. PLC). This supports the pyramidal architecture (sensors → PLC → SCADA) for the Tankvision system.

Lyapunov [14] explains the stability of dynamic systems using Lyapunov functions, which provided the method for testing stability in nonlinear systems using a scalar function. This implies that Tankvision guarantees stability in distributed control algorithms and fault tolerance.

On the other hand, M. Wooldridge [15] studies the fundamentals of multi-agent systems (MAS) and coordination between autonomous entities. This theory allows communication protocols to achieve global objectives in decentralized systems. This explains the integration of sensors and modules using protocols such as HART and Modbus for the Tankvision system.

Protocols are used to verify the accuracy [16] of measurement systems in the oil industry (ISO 13879). The standard defines cross-validation methods between instruments. This enables regulatory compliance in data consistency and audits for the Tankvision system.

Technologies such as digital twins and blockchain have been introduced in the oil industry. They have become key tools for optimizing the operation of crude oil tanks, allowing not only more accurate and secure control, but also facilitating decision-making based on reliable, real-time data.

Digital twins combine physical modeling and ML, enabling predictive analytics, and their integration creates self-verifying and adaptive systems, which are key to Industry 4.0 in hydrocarbons [17]. Blockchain is based on distributed consensus and cryptography, ideal for security and transparency [18, 19].

Another important aspect of inventory systems is operational safety. The report by the IEA [20] addresses safety standards for automated hydrocarbon storage and highlights best practices from the Organization for Economic Cooperation and Development (OECD). The document emphasizes guidelines for automated systems, such as the use of SIL-3 alarms and electronic seals, which is relevant to the safety protocols implemented in Tankvision.

4.2. Tankvision Modular Architecture

4.2.1. Modular Design

Each component is interchangeable and scalable and enables a range of functions: local data acquisition and calculations (level, temperature); aggregation of data from multiple tanks, enabling redundancy and fault tolerance [14]; and integration with SCADA/ERP, facilitating multi-agent communication [15].

The modular system offers significant flexibility advantages, allowing it to be adapted to different types of tanks (atmospheric, cryogenic, or pressurized), while ensuring fault tolerance through operational redundancy. The architecture is structured in two fundamental layers:

- Physical layer that integrates digital sensors using HART 7 or Fieldbus protocols (in accordance with the IEC 61158 standard).

Logic layer based on finite state machines (FSM) that dynamically model processes using state equations, considering variables such as current level, control inputs, and environmental disturbances.

For regulatory compliance, the system implements:

Real-time validation algorithms that compare multi-sensor measurements (with a tolerance of ±1 mm according to ISO 13879).

Encrypted records with RFC 3161 timestamps for auditing (aligned with API MPMS Chapter 18).

Additionally, it incorporates configurable parameters such as thermal expansion coefficients (according to API MPMS 11.1/ASTM D1250) and alarm thresholds adaptable to regional regulations.

5. Integration of Tankvision's modular and distributed architecture from control theory

The Endress+Hauser solution for hydrocarbon inventory is based on a distributed modular architecture, based on principles of hierarchical control theory and dynamic systems. Its technical integration and theoretical basis are explained below.

The fundamentals of applied control theory and its control hierarchy in industrial systems have an architecture that follows a pyramidal model (IEEE 61158), where each layer performs specific functions:

- Field Level (Devices): Sensors (radar, RTD) and actuators (valves).
- Control Level (PLC/RTU): local processing (nivel PLC/RTU) y centralised processing (nivel SCADA). (e.g., API calculations).
- Supervision Level (SCADA/Tankvision): Decision-making and global optimization.

6. Communication Protocols

Communication protocols are classified into two main categories according to their interoperability: closed protocols, developed by specific manufacturers for exclusive use between devices of their own brand, and open protocols, designed under universal standards that allow the interconnection of equipment from different manufacturers, provided they comply with the required technical specifications [21]. For this project, open protocols have been selected to ensure flexibility and compatibility, including HART (with EEx ia certification for explosive environments), Fieldbus (such as Modbus or Foundation Fieldbus V1) and Ethernet (for LAN connections), thus ensuring robust and standardized communication between all system components.

7. Proposal and discussion of automation with Endress+Hauser technology

Hydrocarbon inventory management faces critical challenges: Quality of measurement, operational safety, and regulatory compliance (API, OIML, ISO).

7.1. Challenges of the Tankvision inventory system

The solution presented by addresses these challenges through: State-of-the-art instrumentation for physical measurement of key variables (level, temperature, density); Tankvision software, an IoT platform that unifies data, applies API/ASTM standards, and generates auditable reports; modular architecture adaptable to various types of tanks (atmospheric, pressurized, cryogenic tanks) and scalable for large terminals.

7.2. Details of the advanced instrumentation

7.2.1. Level measurement: Submillimeter accuracy

- Guided wave radar (TDR) – Micropilot S/M

- Servo-meters (Proservo NMSS3)

7.2.3. Temperature: thermal-stratification profiles

- Multipoint RTD sensors (NMT 539)

7.2.4. Density and pressure: Inline measurement

- Radar Hydrostatic sensors (Cerabar S PMP71 hydrostatic pressure transmitters)
- Vibrating densimeters:

7.3. Tankvision software

The integration of inventory management systems with regulatory compliance offers significant operational advantages, notably an intuitive interface for operators and a web-based architecture that eliminates the need for specialized software. Its modular, e design allows for scalable adaptations, while remote maintenance and configuration via LAN (Local Area Network) optimize system availability.

These platforms incorporate advanced features such as volumetric calculations under API standards for storage tanks and Hostlink connectivity for integration with PLC controllers and DCS systems. Additionally, they facilitate spare parts and repair management, ensuring operational continuity. Due to their accuracy and traceability, they are ideal for inventory control and fiscal transactions, complying with international standards such as API MPMS and OIML.

7.4. Distributed architecture

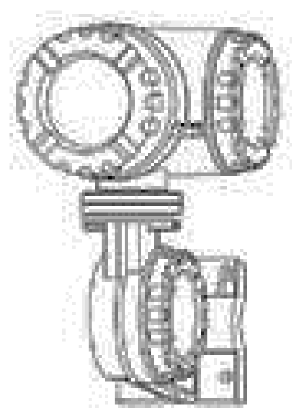
Centralized monitoring, by means of specialized field devices, of critical operating parameters allows the main process variables to be grouped together in a single interface, facilitating their visualization and analysis. These monitoring devices, designed to be installed in strategic locations such as areas adjacent to tanks, provide a clear and accessible presentation of critical data.

For this specific application, the Tank Side Monitor NRF590[22] model has been selected, a device capable of displaying detailed information in real time on: the level of stored product, thermal measurements (both spot and average), the presence of water through capacitive detection, and hydrostatic pressure values (Figure 1). This technological integration optimizes operational control by providing a unified view of multiple parameters that are fundamental to the efficient management of storage tanks.

Key features:

- Technological integration: Unifies multiple variables in a single interface
- Accessibility: Design oriented towards strategic, easily accessible locations
- Technical capabilities: Detailed specification of monitored variables
- Concrete solution: Specific mention of selected equipment with visual reference

Figure 1: Tank Side Monitor NRF590. [22]



For inventory management and control, the Tankvision system has been implemented, an innovative technological solution that operates through a web platform accessible from any standard browser, thus eliminating the need for specialized software and costly licensing. This system is characterized by its distributed local area network (LAN) architecture, which ensures flexibility and scalability to adapt to different operational scales, from small facilities with few tanks to industrial complexes with hundreds of tanks.

The NRF590 monitor concentrates the data from a tank and transmits it to the custody-transfer approval per NMi and PTB standards NXA820 via a field communication protocol. One custody-transfer approval per NMi and PTB standards NXA820 will be implemented for every eight tanks. The

Technical implementation is carried out using the Tankvision custody-transfer approval per NMi and PTB standards custody-transfer approval per NMi and PTB standards NXA820, NXA821, and NXA822 field devices [23], which make up the system's hardware architecture, Its modular design allows for efficient integration with management software, offering a comprehensive solution for real-time inventory monitoring and control. This combination of web accessibility, architectural scalability, and specialized components positions Tankvision as a versatile and cost-effective tool for storage asset management (Figure 2).

Key advantages offered by Tankvision:

- Universal accessibility: Web interface with no proprietary software requirements
- Scalability: Adaptable from small installations to large industrial complexes
- Modular structure: Allows for progressive growth according to operational needs
- Cost-effectiveness: Eliminates expenses associated with specialized licensing

Figure 2. System with Tankvision NXA820, NXA821, NXA822 field devices. [23]

These field devices store the measurements transmitted by the field instruments. The internal software performs the arithmetic operations necessary for real-time inventory calculation and stores the information in the database. The information can be transmitted over the distributed architecture network or extracted via a computer. This system does not require proprietary software or costly licenses.

The Tankvision custody-transfer approval per NMi and PTB standards custody-transfer approval per NMi and PTB standards NXA820 scans the parameters from the measurement equipment in tanks and performs the corresponding calculations for each tank. Suitable for small tank farms with only a couple of tanks, but also for large refineries with hundreds of tanks. It offers the following advantages:

- An industrial operating system with integrated software ensures high stability and availability
- Approved for custody transfer (billing) applications according to international NMi and PTB standards
- Modular design, easy to adapt to any application; can be upgraded at any time
- Configuration, commissioning, and operation from an Internet browser; no proprietary software required
- Access for up to 10 users per Tankvision component from any connected PC, no license required
- Predefined or customized screens for each operation according to typical tank farm operation
- Common hardware platform for all components; no hard drives or fans, no wear and tear

The NXA821 Data Concentrator field device summarizes data from multiple NXA820 Tank Scanners as part of Tankvision. The NXA822 Host Link field device provides data to data hosting systems (e.g., PLC or DCS systems) via Modbus, forming part of the Tankvision system.

The industrial network of the proposed system must have the field devices interconnected as shown in Figure 3.

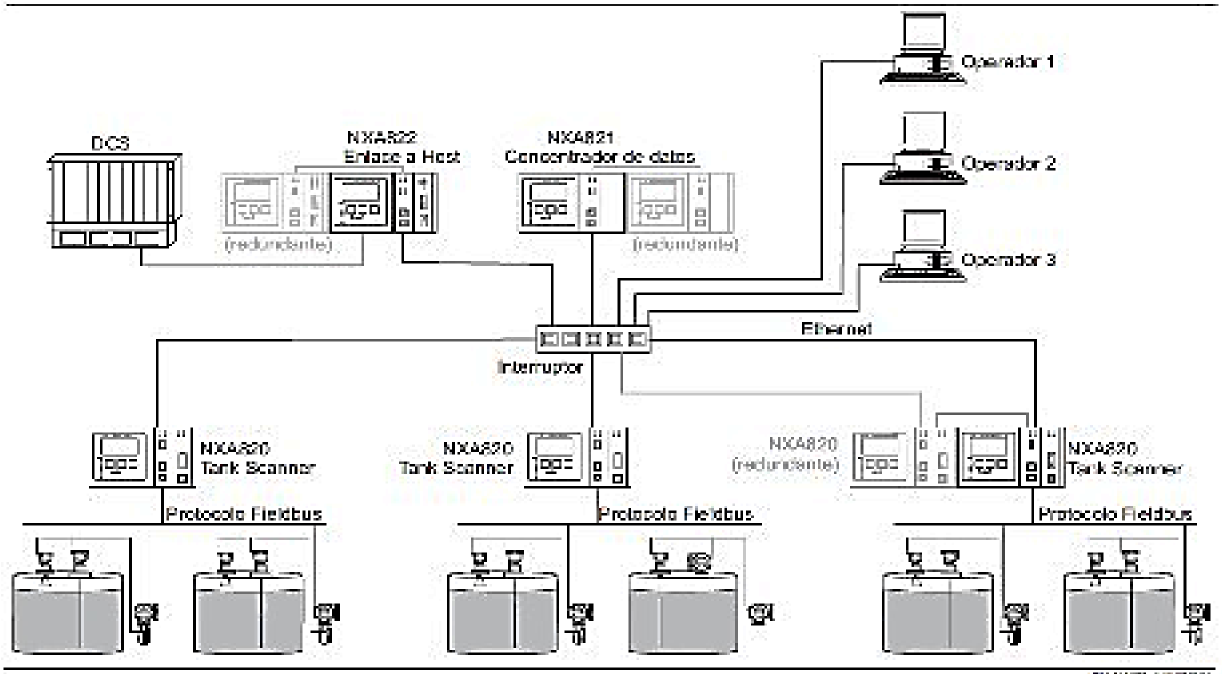
7.4. Automated correction algorithms

The outputs of the automated correction algorithms calculate the standard net volume (SNV) at 15°C and the calculated mass with corrected density.

7.5. Safety optimization and loss reduction

The risk prevention strategy is based on advanced monitoring systems that ensure safe operations and minimize losses. This includes real-time alarms and that detect critical events such as: overfilling (when levels exceed 95% capacity), leaks (identified by anomalies in differential pressure), and fires (monitored through integrated thermography). In addition, RFID electronic seals (RFID electronic seals) are implemented, which prevent unauthorized opening of covers, thus reinforcing the physical integrity of the equipment and operational safety. This combination of technologies not only mitigates risks, but also optimizes asset management through proactive protocols.

Figure 3. Industrial network architecture of the inventory system. [23]



8. Conclusions

The solution proposed by Endress+Hauser with the Tankvision system marks a milestone in the automation of hydrocarbon tank inventories by integrating three key components:

1. High-precision instrumentation, such as radar, servo technology, and RTD, with calibration traceable to international standards.

2. Tankvision, an IoT platform that centralizes measurements, applies API algorithms, and ensures traceability.

3. Robust security protocols to mitigate operational and financial risks.

Future lines of development include integration with blockchain to certify transactions in an immutable manner and the use of digital twins for predictive analytics. These technologies enable the creation of self-verifying and adaptive systems [24], which are fundamental to the successful implementation of Industry 4.0 in the hydrocarbon sector.

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