UNIVERSIDAD DISTRITAL
FRANCISCO JOSÉ DE CALDAS

Visión Electrónica
Más que un estado sólido
https://doi.org/10.14483/issn.2248-4728

VISIÓN ELECTRONICA
A Current Vision

State of knowledge on bidirectional sphere tests (BST)

Estado de conocimiento sobre probadores bidireccionales de esfera (PBE)

Brayan Steve Muñoz-Rojas[1], Andrés Escobar-Díaz[2]

INFORMACIÓN DEL ARTICULO

Enviado: 19/10/2019
Recibido: 07/11/2019
Aceptado: 20/12/2019

Keywords:
Pulse interpolation,
Double chronometry,
Tester, dial,
Reversing valve,
Sensors,
Waterdraw.

Palabras clave:
Interpolación de pulsos,
Doble cronometría,
Probador,
Esfera,
Válvula inversora,
Detectores,
Waterdraw

ABSTRACT:

This document develops the exploratory study that leads to establishing a state of knowledge about standardized BST. The central theme was categorized and subcategorized using the index method - validated by the ORCA research group in 2018 -, having as a guiding norm the generation by the American Petroleum Institute (API), and using as keys: the concept, the principles of operation, criteria and constructive characteristics, the classes, and the norms that govern the testers by displacement. The selected sources have as origin Manuals construction and calibration companies, Patents, industrial texts and academic theses. It is concluded that in future research on BST it is necessary to deepen the tests and calibrations for specific productive purposes

RESUMEN

El presente documento desarrolla el estudio exploratorio que condujo a establecer un estado de conocimiento sobre PBE estandarizados. El tema central se categorizó y subcategorizó usando el método por índices - validado por el grupo de investigación ORCA en el año 2018-, teniendo como normatividad orientadora la generada por el Instituto Americano del petróleo (API), y usando como claves: el concepto, los principios de funcionamiento, criterios y características constructivas, las clases, y las normas que gobiernan los probadores por desplazamiento. Las fuentes seleccionadas tienen como origen Manuales empresariales de construcción y calibración, Patentes, textos de carácter industrial, y tesis académicas. Se concluye que en las investigaciones futuras sobre PBE se requiere profundizar en las pruebas y calibraciones para fines específicos productivos.

1 Mechatronics Technologist, Control Engineer, Universidad Distrital Francisco José de Caldas, Colombia. E-mail: bsmunozr@correo.udistrital.edu.co
ORCID: https://orcid.org/0000-0002-7615-5389
2 BSc. in Electronic Engineering, Universidad Distrital Francisco José de Caldas, Colombia, MSc. in electronic engineering and MBA, Universidad de los Andes (Colombia). Current position: Professor, Universidad Distrital Francisco José de Caldas, Colombia. E-mail: aescobard@udistrital.edu.co
ORCID: https://orcid.org/0000-0002-7615-5389
Cite this article as: B. S. Muñoz-Rojas, A. Escobar-Díaz, "State of knowledge on bidirectional sphere tests (BST)", Visión Electrónica, vol. 2, no. 2, Special edition, 2019. . https://doi.org/10.14483/issn.2248-4728

1. Introduction

For the first successful extraction of an oil well in 1859 -by Colonel Edwin L. Drake in the USA- oil was not a significant resource in the world; this circumstance was triggered, rather, with the appearance of the first automobiles in 1895 which needed gasoline. This new fuel, ignored for centuries, took on a vital role in people's daily lives. But since automobiles were of little functionality and high cost, it was not until Henry Ford revolutionized the entire automotive industry with the launch -in 1922- of his famous model "T"; for that year he managed to sell millions of automobiles: by 1938 there were 40, and in the 50's -only in the U.S.A.- he surpassed the 100 units sold, [1].
As a result, the demand for oil -which increased to extraordinary levels- made it necessary to normalize the exploitation and adequate use of the resource, under the highest quality standards; this is how the American Petroleum Institute -API- was created as a regulatory entity. The API fulfills functions -including- extended to negotiation with regulatory agencies, research on economic, toxicological and environmental effects, among many others, [2].
Likewise, the API currently finances and directs research related to industrial aspects: process optimization, reduction in CO2 emissions, mitigation of the greenhouse effect, among others. It is in this context that the BST, figure 1, appear as calibrated pipes through which, with the help of adequate instrumentation, it is possible to know the amount of liquid that circulates in a pipe during a certain time. It consists of a sphere that moves as the fluid passes through the pipes, activating sensors located at the end of the section of a calibrated pipe, initiating a pulse count that stops when another sensor is activated at the other end of the pipe. BSTs, therefore, are used for the hydrocarbon industry and, in general, are of vital importance in industrial processes where fluid monitoring or control is required.

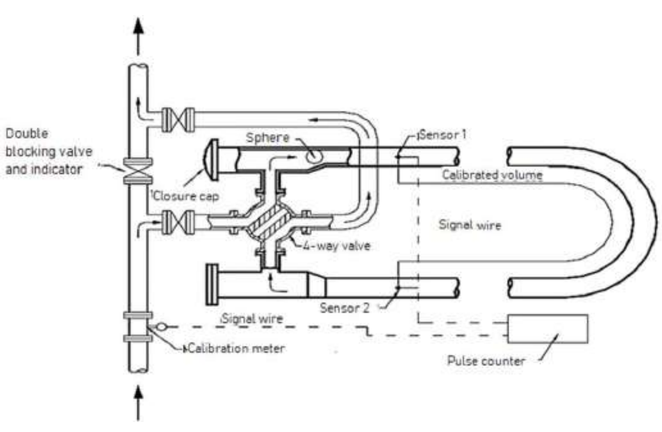

Figure 1. BST [3].

However, despite the fact that the described instrumentation process has been normalized, the information available in the academic literature about the state of knowledge about SBPs is fragmented; therefore, systematic studies are required to address issues that integrate the basic principles of the testers, their design, as well as industrial standardization -calibration-, in such a way that the reader focuses adequately on the maintenance and engineering of SBPs.
Therefore, this paper describes research that updates the state of knowledge, using as a strong core the details provided by the API and its standards.
The document is structured in the following way: initially the methodology of the documentary investigation is established. Subsequently the results are mentioned where topics are described as: API standards, displacement tester concepts, components, operating principles, criteria and constructive characteristics; then the calibration forms of a BST are generalized; and finally the study conclusions are established.

2. Methodology

In order to establish the categories and subcategories developed in this revision, the index method is used [3]. In the previous methodological sense it is found that the development of new technologies on BST has increased, standing out aspects that appear in the API standardized measures manual (API MPMS chapter 4), [4], such as: accessories and characteristics, design criteria, construction criteria, calibration.
From this perspective, **for Accessories and characteristics** the corresponding subcategories: transmitters, spheres, valves and coatings, materials and operating principles; **Design criteria** of a BST is subcategorized into: pre-run, base volume, portability, seasonality and length between sensors; **Construction criteria** is subcategorized into: detection, detection types, interfaces, pulses, interpolation, chronometry, diameters, flanges, minimum and maximum speeds. Finally, for **Calibrations**, subcategories such as: waterdraw and master meter are highlighted.
Accordingly, a review paper is structured based on searching for sources in; the IEEE database, and in Google Scholar, Google Patents, and Google Books. For the documents analysis of this research, of exploratory and documentary character, sources were assumed in each one of the categories and subcategories; geographically it is circumscribed to the European continent and North America. The selected sources originate from Construction and Calibration Business Manuals, Articles, Patents, Industrial Texts, and Academic Thesis; tables 1, 2, 3, 4 and the conceptual map in Figure 2 show this taxonomy.

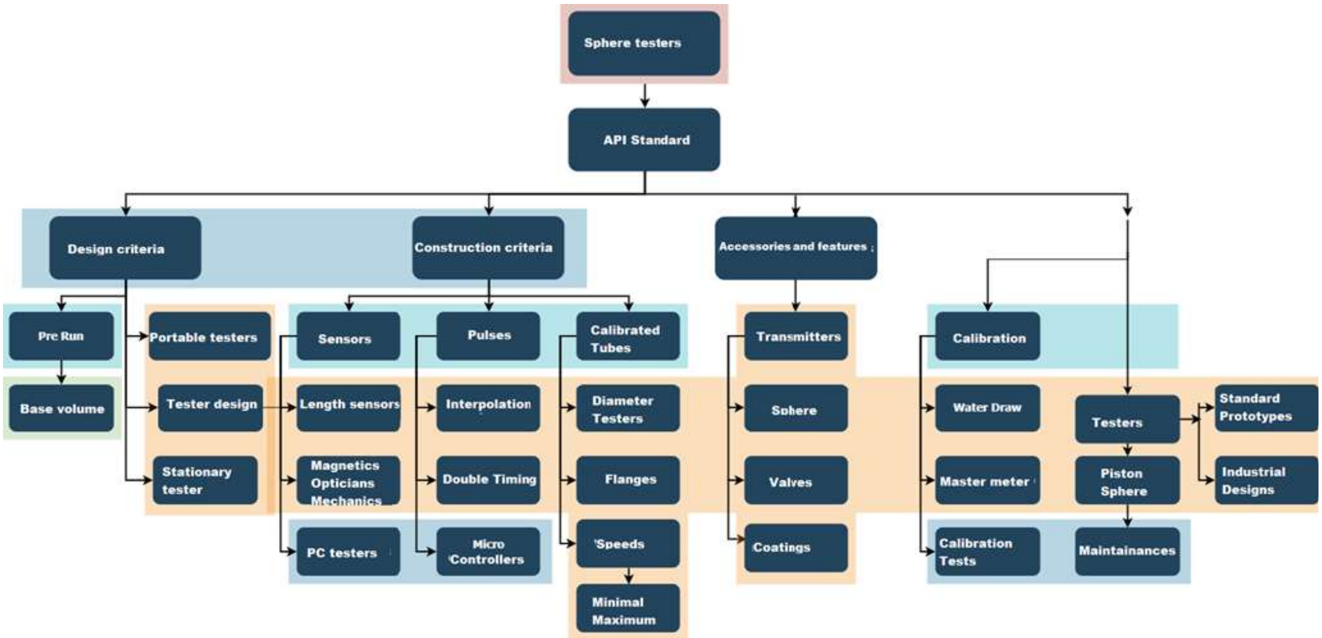

Figure 2. Conceptual map of BST categorization and subcategorization. Source: own.

Table 1 lists the API chapters dealing with testers (chapter 4): introduction to testers' standards, testers' performance, quality standards and accessory reports by manufacturer.

API Standards, Performance and Accessories

API Standards, Performance and Accessories
[1][2][3][4][5][6][7][8][9][10][11][12][13]
[14][15][25][16][17][20][21][24][25]
[26][30][32][33][39][35][37][38][39][40]
[78][79][80][85][87][94][95][97][100]

Table 1. Sources from API Standards, Calibration and BST Operation. Source: own.

In Table 2, for the category Design Criteria, the related sources are considered.

Design Criteria
[21][22][23][24][29][30][31][33][35][36][37][38]
[39][40][41][45][46][47][48][49][50][51][52][53]
[55][66]67][70][72][73][79][85][88][90][93][96]

Table 2. Sources for BST Design Criteria. Source: own.

In Table 3, for the category Construction Criteria, the related sources are considered

Construction Criteria
[7][9][13][14][15][16][18][20][22][23[[[25]26]
[27][28][31][34][36][37][46][42][44][50][51]
[52][54][56][57][58][59][60][61][62][63][66][67]
[69][70][71][73][74][75][76][77][78][80][83][84]
[86][87][88][89][90][91][92][94][95][97]

Table 3. Sources for BST Construction Criteria. Source: own.

In Table 4, for the calibration category, the corresponding sources are listed

Calibration
[1][3][5][16][18][19][20][21][22]
[36][41][42][45][46][47][49][50]
[55][60][62][65][67][70][71][74][75]
[76][80][82][89][95][97][98][99][100]

Table 4: Sources for BST Accessories and Features. Source: own.

3. Development

3.1. API MPMS

These are standards applied to the hydrocarbon measurement, [5]; the API MPMS are reviewed and reaffirmed every 5 years, sometimes even every two years [6]. Chapters 4.2 to 4.9.2 are identified. - Calibration Methods for Displacement and Volumetric Tank -. The BST, used to improve instrumentation in the oil measurement process. The API is the reference point for research related to BST.

3.2. Testers

The testers are used as a reference standard for the Flow sensors calibration. There are three types of testers: master tester, test tank, and displacement testers, [7].

3.2.1. Positive displacement testers

These testers consist of pipes or cylinders whose measured volume serves as a standard for calibrating flow sensors, [8]. The fundamental part of these testers are their calibrated pipes, [9], which are of a certain diameter and the flow that happens in a certain time is known, [10]. They are equipped with sensors that detect the passage of a sphere or piston, [11]. When the sensor is activated, pulses are emitted, which are compared with the sensor to be calibrated, illustrated in figure 3, [12]. There are two types of testers: ball and piston; and in turn each of these can be unidirectional or bidirectional displacement testers, [13].

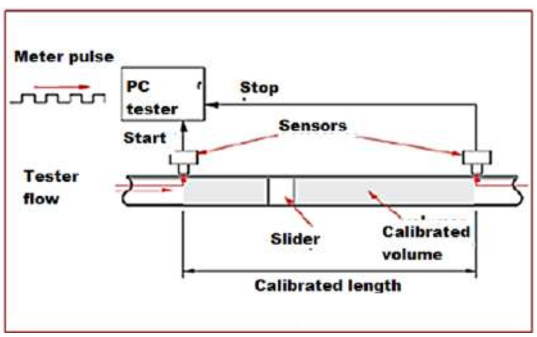

Figure 3. Displacement Principle [6].

Functionally, in a section of calibrated pipe the liquid enters by pushing a sphere along it, [14]. At the beginning and end of the calibrated pipe are located the sensors which are mostly inductive or mechanical, [15]. The sphere, when passing through the first sensor (start) starts a pulse count and is stopped until the sphere passes through the second sensor (stop), [16]; this is called the first run, [17]. In bidirectional testers the sphere circulates in a roundtrip direction, the total of counted pulses are compared with the sensor to be calibrated, [18].

3.3. BST accessories and features

Quoting directly from the Hydrocarbon Measurement Manual chapter 4, test systems; bi-directional testers have the following accessories and features:
At least one quick-release cover (installed in the sphere release chamber) see figure 4. With pressure indicator device, capable of covering the maximum system pressure, [20].

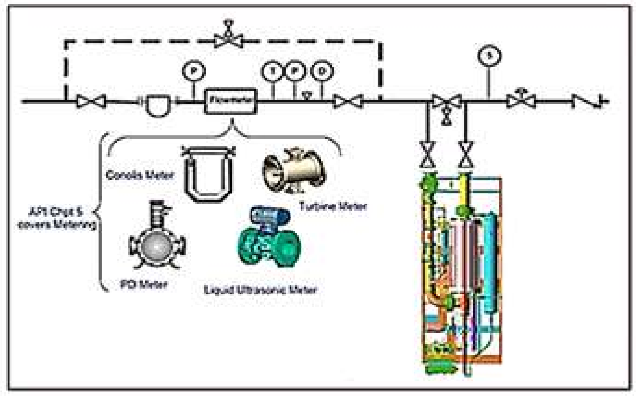

Figure 4. Complete diagram of a displacement tester [11].

- Tester inlet blocking valve.
- Pressure and temperature transmitters, pressure gauges (optional) and connection for thermometer. Certificates on the inlet and outlet of the pressure tester to control this variable inside it, [22].
- Sphere: the materials used in the construction of elastomeric spheres change according to the applications for which they are used, [23]. Those commonly used have three basic materials: neoprene, nitrile and urethane. They are in charge of activating the sensor switches and transporting the calibrating liquid volume, [24].
- The tester must be protected internally with material that provides a solid, smooth, and durable finish, reduces corrosion, and extends the life of both the displacer and tester, [26].
- Launch chambers that send the sphere in the test run, as well as slowing it down when it reaches them, [27].
- 4-way reversing valve for bi-directional testers, [28].
  The related instrumentation is represented in the figure 5.

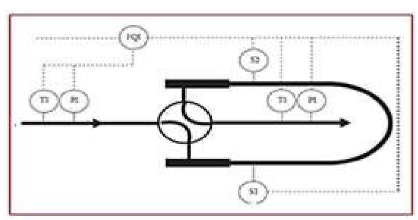

Figure 5. BST Instrumentation [20].

3.3.1. BST operating principle

Its operation is based on the displacement principle, as follows: it initiates the flow in the main line and the fluid passes through the meter, [30] - figure 6 -. The inlet - figure 7 - and outlet - figure 8 - tester valves are opened and the flow block is activated, closing the valve in the line, [31].

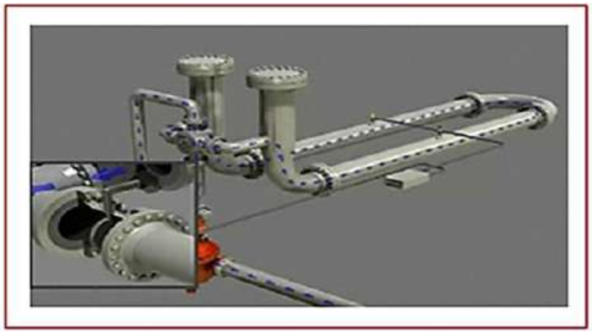

Figure 6. Flow block on the main line [21].

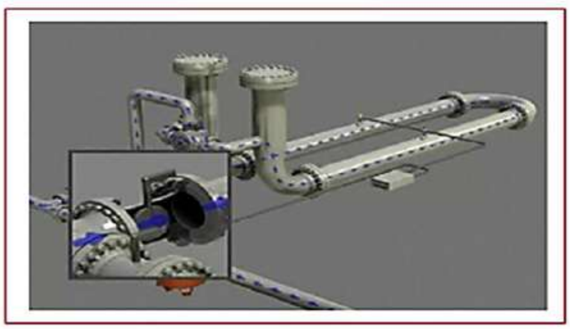

Figure 7. Tester inlet valve opening, [21].

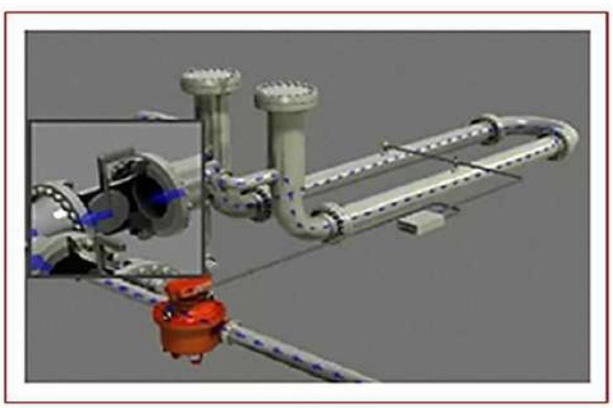

Figure 8. Tester outlet valve opening [21].

The above is done to allow flow through the tester without interrupting the normal course, [33]. This is how the BST for meter verification comes into operation. The fluid that has just passed through the meter (or less commonly, the fluid on its way to the meter) pushes the sphere along a compact tester, [34] - Figure 9-.

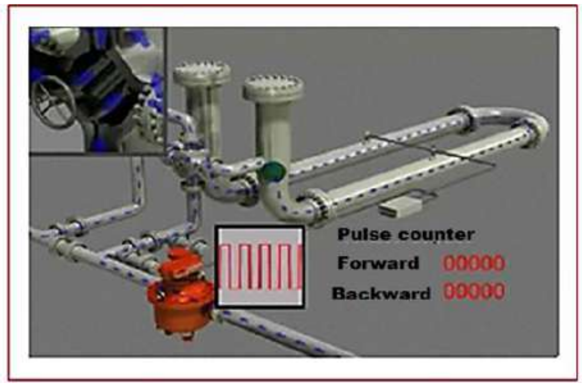

Figure 9 Four-way valve opening [21].

As for the tester, the sphere makes a hermetic seal against the tester's wall, [35], as follows:

- When the sphere enters the known volume section, see figure 10. A sensor detects its proximity and sends an electrical signal that opens an electronic gate to admit and count the pulses that are emitted by the meter, [36].

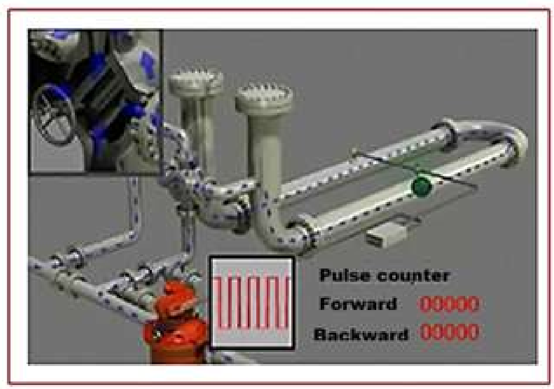

Figure 10. The sphere runs through the known volume section [21].

- When the sphere leaves the known volume section then a second proximity sensor sends the electrical signal to close the electronic gate and end the pulse count. See figure 11.

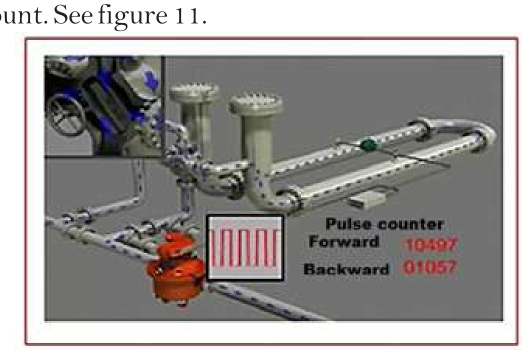

Figure 11: Just when the sphere activates the second proximity sensor indicates that it has exited the known volume section. [21].known volume section.

- After making the necessary corrections. The total number of pulses accumulated during the round trip volume is compared with the basic volume of the tester. Figure 12.

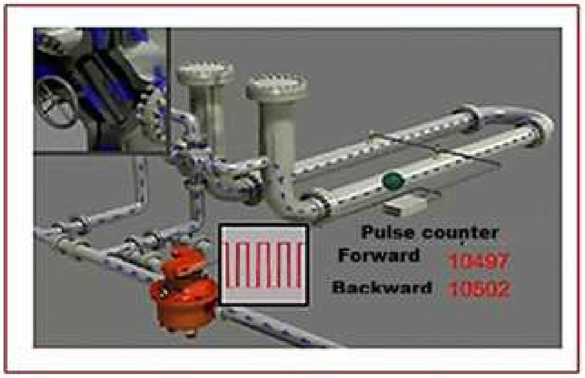

Figure 12: Counted two-way pulses are compared [21].

- In bi-directional testers, the problem of returning the sphere to the starting point is solved by a 4-way valve with which the flow through the tester can be reversed without interfering with the flow.

To avoid hydraulic shock, the 4-way valve is designed in such a way that the fluid flow is not interrupted at any time during valve operation, [38]. Under these conditions, the ball begins to move to the known volume zone while the 4-way valve continues to rotate, [39]. Under these circumstances it is necessary to be sure that the 4-way valve has completed its movement before the sphere reaches the first sensor, [40]. To ensure that this happens, an uncalibrated portion of the pipe is left between the sphere's rest position and the sensor. This tester portion is known as the pre-run section, [41].

3.4. Design Criteria

For BST design criteria based on API MPMS chapter 4.2, and have a correct basic engineering [43], has to be verified:

- Whether the bidirectional tester will be fixed or mobile.
- If it will be in continuous service or isolated from the flow, when it is not in use.
- The pressure and temperature ranges must be related to the design.

3.4.1. Internal pipe coating

Internal coatings are applied for two main purposes, [45]:

- Protect the pipe from corrosion and pitting to avoid repeatability problems.
- It provides a smooth surface so that the sphere can be moved with a stable moving seal, without surges or jolts, [46].

The coating types used in testers are, [47]:

. Air-drying epoxy
. Baked phenolic
. None - Nude (raw service)

3.4.2. Tester's base volume

For the BST. The base volume is expressed as the sum of the calibrated volumes between sensors in two consecutive passes, [49]. Each pass must have the standard temperature and pressure. The BST base volume can be determined with three or more runs. Each of these runs must be consecutive and repeat within a range of 0.02%. [50]. BSTs are known for their high capacity to store liquid between tests, [51]. Some of the BSTs are represented in Figures 13, 14, 15.

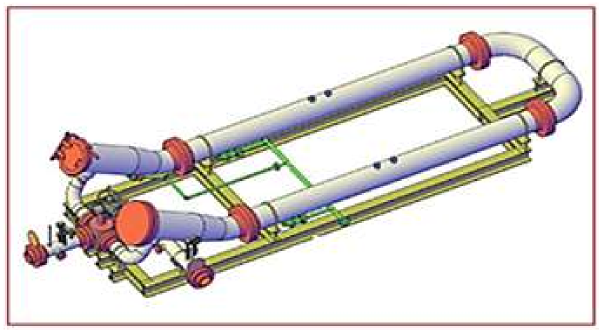

Figure 13: U-type sphere tester [24].

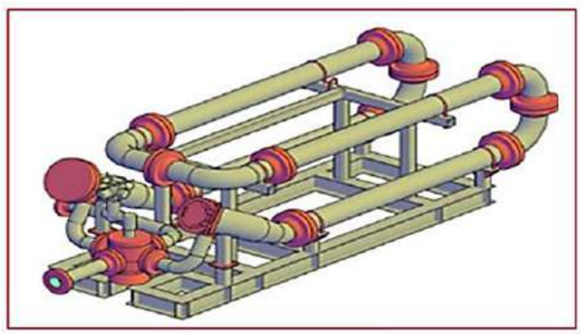

Figure 14: scorpion-type sphere tester [24].

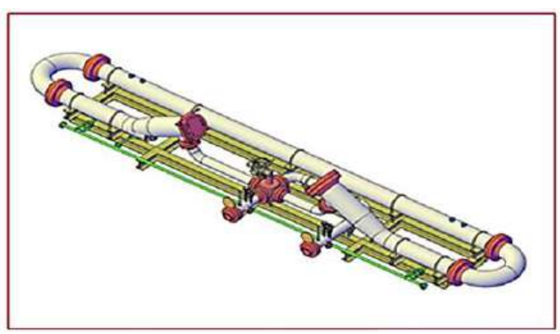

Figure 15: Calibrated straight section type sphere tester [24].

3.5. Construction Criteria

In the document, API MPMS chapter 4 section 2 "Proving Systems - Displacement Provers" refers specifically to this type of testers, and must be built according to standards based on the API using as a basis the following criteria:

3.5.1. Sensors

The sensors must have as a quality that they can detect the materials that make up the sphere or piston, [53]. In some cases they will work in submersible conditions [54]. Some sensors found in the market of testers are:

3.5.1.1. Mechanically operated sensors

It is mainly used with elastomer sphere shifters. Generally actuated when the BST makes contact with a stainless steel rod or ball protruding from the test pipe, [55]. An electronic switch is activated to indicate the passage of the sphere through the calibrated pipe section. The sensor switches are hydraulically balanced, this prevents the switch from being activated with a pressure spike, [56].

3.5.1.2. Optically operated sensors

These are used in both types of testers -sphere and piston-, but generally in the piston type, [62]. They are also mounted on the pipe without the need to thread them. The optical sensor design has a light source along with a photoelectric sensor cell, mounted on the opposite side, [63].

3.5.2. Length between sensors

The repeatability of the sensor is crucial in determining the tester volume. The most common testers are mechanical action testers. To know the most appropriate distance from the sensors position, it is necessary to know the sensor resolution (DR), [65] -provided by the manufacturer-. The maximum distance traveled by the sphere in a single trip is calculated as, the distance between sensors plus twice the resolution. The minimum distance is calculated as the distance between sensors minus twice the resolution, [66].

3.5.3. Tester speed

This is the speed at which it is required to move the sphere in the calibrated pipe. Having to establish maximum speed of the sphere, to prevent damage, (in the sensors and friction with the pipe), [67]. With this criterion there is better repeatability, accuracy and reproducibility of the measurement factors. Just as the maximum speed is considered, the tester should be analyzed working at minimum speed, especially in liquids that have low lubricating capacity, [68].

3.5.3.1. Tester maximum speed

For sphere testers - according to API MPMS in chapter 4.2.- maximum and minimum speeds are specified. At the maximum, 10 feet/sec in unidirectional design and 5 feet/sec in BST are recommended. Higher speeds may be achieved by incorporating a design to limit mechanical and hydraulic shock, [70].

3.5.3.2. Tester minimum speed

At minimum speed it is suggested to bear in mind that if liquids with little lubrication are measured, there is a risk that the sphere will run and stop and run again. A uniform displacement between the calibrated pipe must be ensured. Typical BST minimum speeds for low lubricating fluids such as gasoline and LPG are: 0.5 - 1.0 ft/sec, [71].

3.5.4. Pre-run

This is the pipe length required for the BST. Which allows it to travel from its resting position to the first sensor. The minimum length should allow sufficient time to reach the maximum constant velocity before reaching the tester's calibrated section, [72]. Another function of the pre-run is to provide sufficient time for the flow reversing valve to perform an adequate seal. The valve manufacturer, in its technical data sheet must provide information on minimum travel times, sealing and the maximum speed allowed, [73].

3.5.5. Pulse interpolation

This section explains the installation, operation, maintenance, and troubleshooting of measuring BST pulses. It is so important, because this is the reference standard for calibration, [74]. Related information can be found in API Chapters 4.2 and 4.6. A minimum number of pulses must be collected as the sphere travels through the sensors. The design of the tester is intended to increase the pulse reading discrimination of the flow meter. In order to achieve an uncertainty of 0,01%, [75].

3.5.5.1. Pulse interpolation by double chronometry

The pulse interpolation by double chronometry requires counting the total number of pulses of the Nm flow meter. These are generated, as the sphere passes through the sensors measuring the time intervals, [77]. T1 and T2. T1 is the time since the first sensor is triggered by the sphere step. It stops when sensor number two is triggered. T2 is the time interval between the first and last sensor signals. The time intervals Ti, corresponding to pulses of Nm, illustrated in figure 16. T2 corresponding to the interpolated number of pulses (NI), is measured by a precision clock, [76].

$$N1 = Nm\left(\frac{T2}{T1}\right) \quad (1)$$

It is required that, between T1 and T2 the discrimination is better than ± 0,01 %. The time periods must be at least 20,000 times longer than the reference period Tc, [77]. Clock frequency (Fc). The manufacturer must ensure that it is high enough to be able to accumulate at least 20,000 clock pulses during the test operation. [78].

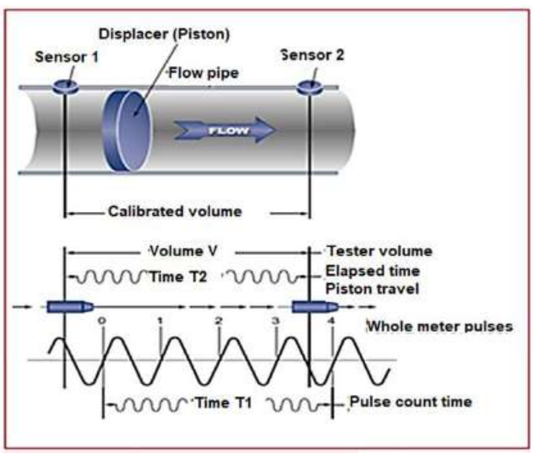

Figure 16. Double Chronometry Diagram [34].

3.6. Calibration

Under no circumstances should mechanical displacement testers exceed calibration times projected at 60 months [79]. Pipe tester calibration involves determining the base volume displaced between sensors. In a BST it is the sum of volumes displaced between the sensors in a round trip, establishing standard conditions of temperature and pressure. The testers can be calibrated in two ways: waterdraw method and by master meter, [80].

3.6.1. Master tester method

The master meter's purpose is to serve as an intermediate link between the pipe calibrator being calibrated and the master tester, [81]. It can be a test tank or a set of calibrated pipes. Therefore, it is necessary to verify before and after the calibration run. A typical restriction of the master meter method is that it should not be applicable to pipe testers with small volumes, [82].

3.6.2. Waterdraw method (Water extraction method)

The waterdraw method consists of passing water through the tester, which will be collected in tanks. It is equivalent to the volume between the sensors of the tester. For this, the 4-way valve and another solenoid type are used. It indicates the sphere passage and thus allows to align the flow towards the tanks. Chapter 4.9 of the API MPMS explains in detail the calibration method. To complete this task, reference standards of the graduated neck volumetric vessel type are used. These vessels have outstanding storage, due to the viscosity effect and the steam tension in the drainage time. See figure 16. In a standard measurement test, water is the only meter that can be used for this method. Water is selected because of its well-defined properties and is readily available, [83].

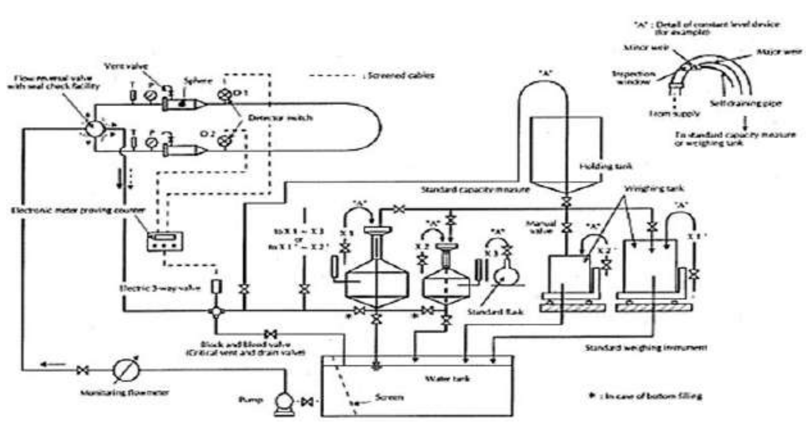

Figure 16. P&ID waterdraw method [81].

4. Conclusions

In this paper a review of the most relevant categories of API Chapter 4 has been done. Creating a framework for future research. For this purpose, the description of the architectural components was carried out, informing the reader of the BSTs importance and functionality. The documentation related to the SGPs consists largely of industrial information, which covers 35% of the total references; followed by academic information such as academic papers, which make up 30% of the total references. The other references are divided by: API MPMS standards with 10%, and patents with 15%: in terms of Patents [84-91]. In degree thesis, [92-99] it is found that it corresponds to 10% of the information.
According to the study an adequate state of knowledge is obtained which can serve as a baseline for BST research; specifically, documentation that addresses issues of testers' basic principles and design with minimal initial knowledge. From the references investigated, it is evident that most of them are testers already constituted in the industry; from which the reader can follow an academic information related to the branch of maintenance or engineering.
As a result of the bibliographic review of the subject, there is a lack of literature in Spanish-speaking countries; therefore, there is an opportunity to continue exploring research from the IPY that contributes to improve in terms of environmental regulations, as well as the incorporation of innovative technology that could lead to new patents and innovation in BST instrumentation. In Colombia, most of the projects developed are at the industrial level and most of the documentation appears in the Colombian company ECOPETROL, so the research will be useful for the associated engineering consultant.

Acknowledgments
To the SciBas and Orca research groups, attached to the Research and Scientific Development Center of the Universidad Distrital Francisco José de Caldas (CIDC), for his advisoring on the mathematical modeling and methodology.

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