



White Paper

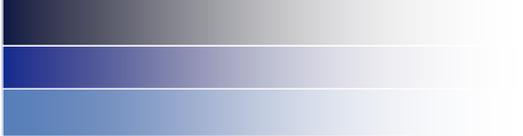
August 18, 2009

Best Practice Servo Tank Gauging for Density Measurement

This document describes the best practices for servo tank gauge installation and operation for comparing measurements from the Varec 6005 Servo Tank Gauge against measurements obtained using manual methods.

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Executive Summary

The Varec 6005 Servo Tank Gauge (STG) offers high accuracy, multi-variable measurement that fulfills the many demands required for tank inventory management. Throughout the industry, there is a need to compare instrument readings against measurements taken by hand. The reason to compare readings may differ from company to company; it may even differ from facility to facility within the same company. The process of obtaining the manual measurements is widely known as “hand dipping the tank”.

This white paper offers recommendations for the installation and operation of the Varec servo tank gauging solution and hand dipping procedure when a direct comparison of measurements needs to be made.

Recommendations for Stilling Well Construction

Varec recommends the installation of a servo tank gauge on a stilling well that is designed and installed to API recommendations in order to obtain highly accurate and repeatable measurements. In the relevant API documents (see references), you can find detailed information on stilling wells. The primary reasons for having a stilling well are:

- Provides a stable gauge reference point and limits vertical movement caused by tank deformation
- Provides a relatively 'quiet' product surface, especially during filling and emptying of the tank
- Prevents floating roof rotation and allows access to the stored liquid product at the same time

Minimum diameter

API suggests an 8" minimum diameter for a stilling well. In general, 8" should be sufficient, but for very large external floating roof tanks, larger diameters of up to 12" should be considered. API notes diameters above 12" are not particularly useful. For relatively small tanks (maximum height 30 ft), 6" diameters can be considered. For horizontal cylindrical (bullet) tanks (maximum diameter 13 ft), a stilling well of 2" diameter can be considered. The 6005 STG can be installed on flange sizes as low as 3" and displacers are available in sizes from 30 mm (1.2") in diameter.

It is advised to make the whole stilling well the same diameter, especially in the case when a radar level gauge is used, but this requirement is less critical with other gauge technologies, such as servo gauges.

Support of pipe

Preferably, the stilling well should be supported out of the tank bottom. In areas where the ground on which the tank sits is very unstable, it is suggested to support the stilling well out of the lowest part of the tank shell (less than 1 foot



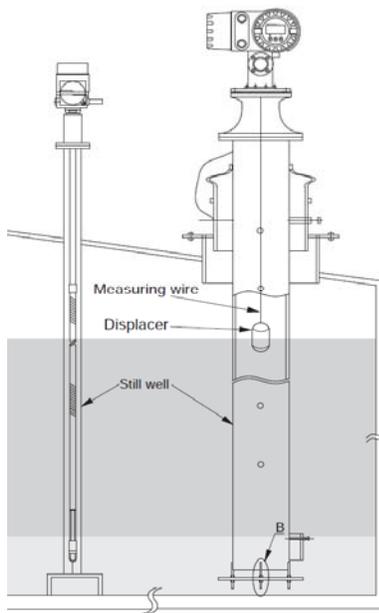
from the tank bottom as shown).

For tank floor support, a simple tripod is sufficient. For tank shell support, it is important that a certain amount of tank 'bulging' (due to hydrostatic tank deformation) can be tolerated without extreme mechanical stress exerted on the tank shell itself.

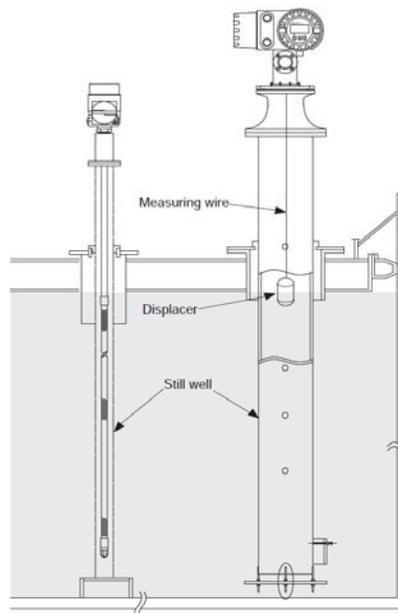
Guiding of pipe

The top end of the stilling well should be properly guided and allow for vertical movement of the tank shell and tank roof in respect to the stilling well. Normally, a construction with three centering bolts is considered to be enough. The bolts can be adjusted for reducing horizontal and vertical tolerances.

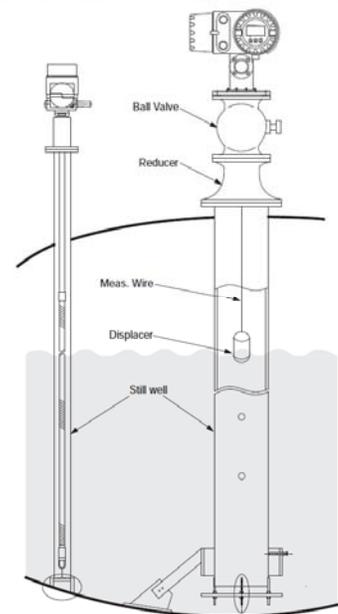
Fixed roof Tank with stilling well



Floating roof tank and /or covered floating roof Tank



High pressure tank with stilling well and ball valve



Lower/Bottom end

The lower end of the stilling well should extend to within 12" of the tank bottom.

Perforations vs. slotted

Slots or perforations are highly recommended on any stilling well used for gauging the contents of the tank, independent of whether it is by manual or automatic means.

Typical hydrocarbons show an average thermal expansion coefficient of 0.1% every °C. Most hydrocarbons can vary largely by composition.

Top – For radar tank gauging, the slots shown are too big - made with a torch. They would affect the radar signals and absolute accuracy. A servo gauge would not be influenced. Bottom - A good example for both radar and servo tank gauging as the grinded slots are not oversized.

If a stilling well is not slotted or perforated, the product in the stilling well will be pushed in from the bottom. This may include water or sediment, which is not representative of the rest of the tank. The product pushed in can have a different temperature and composition than the rest of the tank's contents, therefore, a different base density and observed density. As a result, the product column inside the stilling well, with a different actual density than the average product in the tank, can show a different level per the physical law called 'communication vessels'. A difference as small as 0.1% in density (0.8 kg/m³ on a typical product of 800 kg/m³) in a tank containing 33 feet of product will result in a level difference of 0.5".



Note: It is assumed that the top of the stilling well is 'open' and not hermetically sealed. The opening can be inside the tank and below the roof provided the highest hole or perforation is well above the maximum safe oil level for the tank. Failure to follow these guidelines can lead to serious level errors and, in worst case situations, even to overflow and product spillage.

In the relevant API standard (Ch. 3.1A), two rows of overlapping slots or holes located on opposite sides of the pipe are recommended. For most hydrocarbon applications, it is proposed to have a double row of 1" to 1½" holes on opposite sides of the pipe, with the holes staggered on both sides with a pitch of approximately 2 feet. It is also suggested to let the

holes be radial on the center of the tank (minimizing product flow through the pipe). All holes should be properly de-burred.

For very light products, like LPGs stored in bullet tanks with a 2" to 3" stilling well, the hole diameter can even be further reduced to 0.25" to 0.5".

Location

API recommends that the center line of the stilling well be approximately 18" to 30" from the tank shell *in order to minimize temperature effects from the sun heating the tank shell.*

Grounding

It is essential that the stilling well is extremely well grounded to the tank potential. It is advised to have at least two braided wires between the tank shell and stilling well, preferably one at the bottom and one on the tank roof.

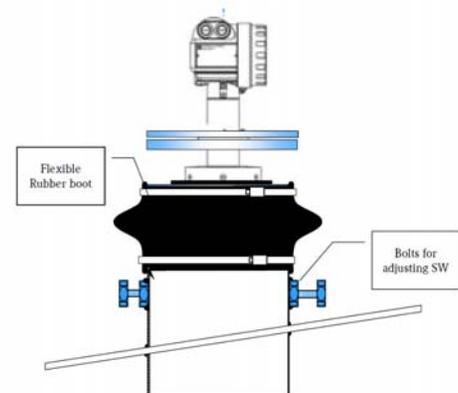
The braided wires should be at least 2" x 0.25" mm and preferably welded or connected with shark rings. A simple nut and bolt is definitely not enough, as paint and rust will prevent proper galvanic contact.

Vapor seals

A vapor seal is recommended in all cases in order to minimize vapor emissions. A simple rubber boot clamped on the well and fixed to the roof is normally sufficient.

Installation of coaxial stilling wells for ATG applications

Note: API is aware that, for some applications, it is advised to insert a secondary stilling well in the originally installed stilling well. This may be due to excessive size of the slots, corrosion, reducers welded to pipe (above or below roof) or the necessity to install an average temperature sensor on the same stilling well.



This issue was discussed in several API workgroup meetings and future standards will reflect the now current joint opinion: Stilling wells used for manual sampling, i.e. stilling wells that are not only used for automatic level gauging, but where product samples are taken out for chemical, physical and/or composition analysis, should not be equipped to have a secondary (coaxial) stilling well inside. It is thought that this would have a negative influence on how representative the product sampled is compared to the average product in the tank.

Hand Dipping

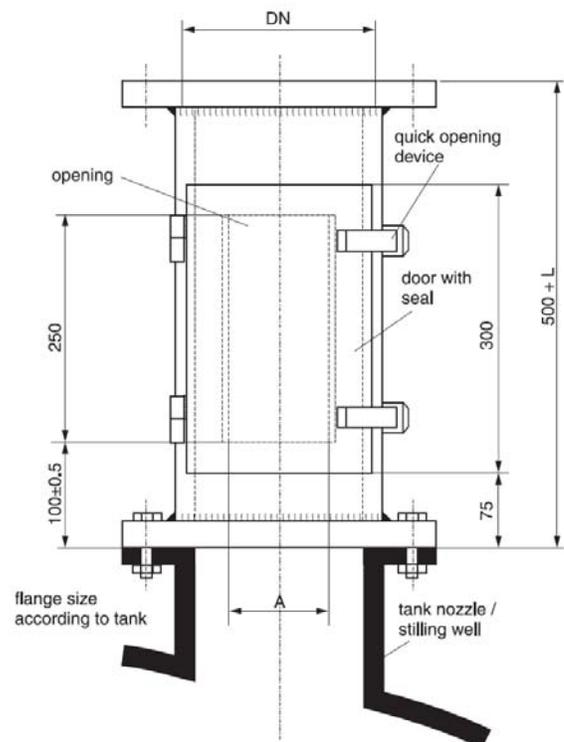
In order to compare any two measurements the external factors affecting the measurement should be negated as much as possible. Therefore, in order to get a true comparison, Varec follows API's recommendation for hand dipping procedures and highly recommends using the exact same stilling well that is used for the 6005 STG measurement. One advantage automatic tank gauging provides over manual measurement is the repeatability of the measurement. For example, one operator may open the sample bottle at the bottom of the tank and leave it open as it is pulled up through the liquid. A second operator may open and close the sample bottle before it is hoisted. A 6005 STG performs the same measurement in the same manner every time.

Using the same stilling well

Although a stilling well is designed to provide a stable platform, differences can still occur when the sample is taken from a different stilling well. The relative positions of the stilling well, variations in construction, as well as tank roof, floating roof and tank shell movements can all affect the measurement result.

Extension/calibration chamber

In order to conduct a hand dip measurement in a stilling well, an additional extension of the stilling well (or calibration chamber) may need to be installed. The extension would then provide an opening large enough to allow easy access for a hand measurement or use of a sampling bottle. The



opening should be simple and uncomplicated without the need for special tools or without parts that can become separated and are likely to be dropped, damaged or lost. Good results are obtained using so called ‘hinged door’ constructions that can be used for both servo and radar technologies.

For installations where vertical visual access into the tank is required, it is possible to use a ‘swivel’ approach. For accurate hand dipping in custody transfer applications, it is recommended to have the reference height of the dip location properly identified next to the dip hatch.

Before performing a hand dip measurement

The 6005 STG displacer should be returned to the home (up) position and the individual performing the manual measurement should confirm its position in the 6005 STGs’ calibration window. If this procedure is not preformed, the instrument tape or sample bottle used for hand dipping may get tangled or caught on the displacer wire and damage the wire, displacer or gauge, resulting in costly repairs.

Servo gauge selection

The extension/calibration chamber height must be added to the overall measuring height to ensure the correct length of measuring wire is available to measure all the way to the tank bottom.

Materials selection

The materials used for construction should be compatible with the product stored. For smaller tanks and small diameter stilling wells (less than 4”), stainless steel can be considered, as it allows for thinner walls and does not require any formal coating or corrosion protection.

Density Measurement Using the 6005 STG

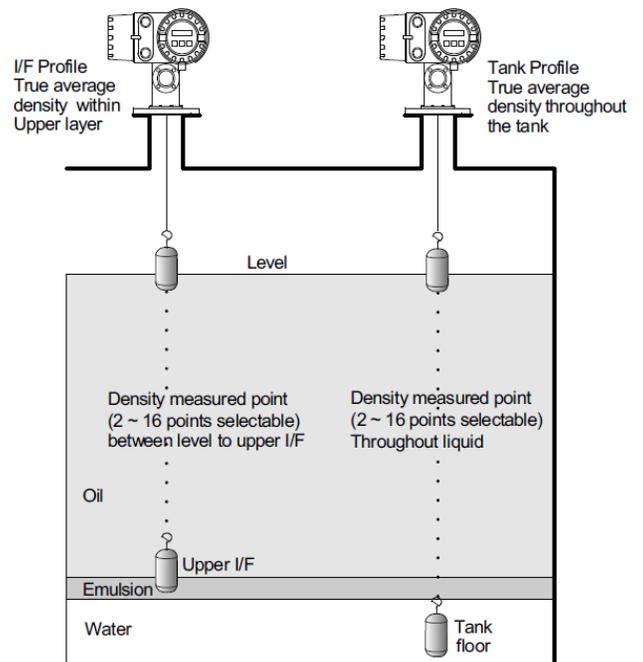
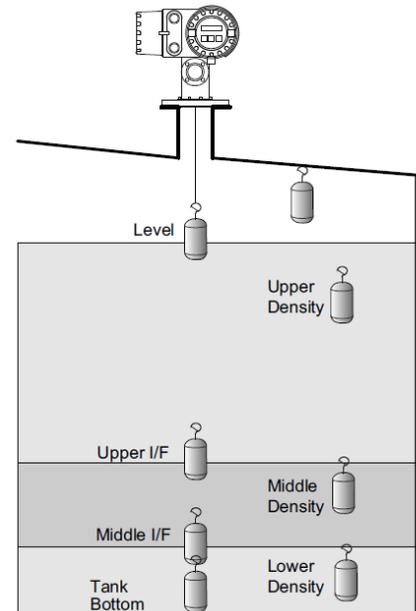
The 6005 STG provides two options for measuring density: spot measurement or density profiling. This specific functionality must be selected at the time of purchase. Both methods provide an accuracy of $\pm 5 \text{ kg / m}^3$ ($\pm 0.005 \text{ g / cm}^3$, $\pm 31 \text{ lb/ft}^3$).

Spot density

When a 6005 STG is purchased with density measurement capabilities, it measures two clear interface levels and specific gravity (spot density) of up to three liquid phases as shown in the diagram opposite. The default measurement position is configured to 150mm below the liquid surface, i.e. the upper density is measured 150 mm below the liquid level and the middle density reading is taken at 150 mm below the upper interface level, etc. If spot density measurements are compared to hand dipped values, the hand dipped measurements should be taken at the corresponding levels.

Density profiling

When the density profiling option is selected at the time of purchase, the 6005 STG is capable of performing two density profiles, as shown in the diagram opposite. This



wide sample provides a more accurate picture of the tanks contents, but is rarely conducted when hand dipping. Each profile can consist of 2-16 different measurement points. The first method, called a *tank profile*, profiles the liquid density from the upper level reading to the tank bottom. The second, called the Interface (I/F) profile, is a density profile of the upper liquid layer from the upper level reading to the upper interface level. For either of these two profiles, the 6005 STG is able to calculate a single “average density” value or supply the individual point measurements to the host system.

Variations in procedures

To improve manual comparisons, the individual points communicated to the host system could be printed and provided to the technicians to help perform multiple hand dips at the same levels within the tank. However, it is likely that the variation in hand samples for a 16 point profile would increase the margin of errors and, therefore, reduce the hand dip accuracy, as well as a direct comparison.

Temperature Measurement

Varec recommends the use of a 4532 Average Temperature Sensor (ATS) in conjunction with the 6005 STG to provide an accuracy density profile. The 4532 ATS contains 2-6 temperature elements, depending on the tank height, for tanks up to 60 ft (18.5 m). The Varec 4539 Average Temperature Sensor (ATS) could be utilized for tanks above this height or for customers that require more temperature elements. Both devices request level data from the 6005 STG. They then combine the values from the submersed temperature elements to provide an accurate average density calculation of the stored product only. They record the temperature at the same time as the level measurement is taken per API recommendations. Unless an electronic level and temperature device is used for manually hand dipping the tank, the two measurements will always differ in time and, therefore, will not be conducted to API standards. It also excludes the temperature elements within the vapor space of the tank; these elements are only used to calculate the vapor temperature.

Product stratification

A single spot temperature sensor can be connected to the 6005 STG if average temperature measurements are unavailable or unsuitable for the application. Due to the stratification of petroleum products in large storage tanks, Varec recommends utilizing average temperature for density measurement applications. Spot temperature measurements do not provide an accurate representation of the temperature of stratified products.

Proximity to the servo gauge

Petroleum products stratify in horizontal layers through the tank. The temperature across the layer is, in all practicality, constant. Therefore, the proximity of the temperature sensor to the servo gauge will not adversely affect the density profile measurement. However, Varec recommends placing the temperature sensor in close proximity (<10 ft) to the 6005 STG stilling well to minimize differences in ambient temperature conditions, such as sunlight heating one side of the tank shell and not the other.

Installation

Varec recommends installing the 4532/9 ATS in a 2" or 3" stilling well on tanks with floating roofs (internal or external floating roof). If a tank does not contain a floating roof, the probe can be anchored in the tank's free space by means of a weight or tensioning wire.

Note! The end of the 4532 or 4539 ATS temperature probe is 400 mm from the tank bottom and the lowest element is always 500 mm from the tank bottom. It is important to ensure that correct tank heights and measurement ranges are supplied to Varec at the time of order. Varec can supply an application data sheet to help identify and record the data needed to correctly order a 4532/9 ATS and 6005 STG.

If a stilling well is used, its construction should also follow API recommendations for location, slots, fixing, grounding and vapor seal use, as highlighted in the previous section of this document.

Configuration

Both the 4532 and 4539 ATS connect to the 6005 STG via 2-wire intrinsically safe HART connection. The devices are "plug and play" and do not need any additional configuration in the 6005 STG or host system.

Summary

Use a stilling well

In order to compare any two measurements of liquids in a large bulk storage tank, the measurements should be taken from the same location on/in the tank. Therefore, Varec recommends performing the hand dip and the servo measurement in the same stilling well. If a stilling well is used, it should conform to API standards.

Amount of measurements

The requirement for hand dipping a tank is widely accepted throughout the industry. Generally, a single sample is taken from a tank when a dip is performed, but for a direct comparison, the amount of hand dip measurements taken and heights at which they are taken should be compared as close as possible to that of an automatic tank gauge.

Temperature measurement

In order to automatically calculate density measurements, the 6005 STG requires an integrated temperature sensor. Varec's 4532/9 ATS provides accurate temperature measurements to API's recommendations for inventory management of bulk liquid petroleum products.

Field communication selection

In order for the 6005 STG to transfer average density or transfer up to 16 individual point measurements to the host system, MODBUS field communication protocol should be used and a 6005 STG with MODBUS as the primary output should be selected at the time of purchase.

Credits

About Varec

Varec, Inc. delivers measurement, control and automation solutions and professional services for most major oil companies, defense organizations and airlines worldwide. Varec's FuelsManager® software applications and hardware products provide local level management and enterprise visibility of liquid petroleum assets at bulk storage facilities, marketing terminals, refineries, petrochemical plants and military fuel facilities.

References

1. Manual of Petroleum Measurement Standards – Chapter 3 – Tank Gauging – Section 1A – Standard Practice for the Manual Gauging of Petroleum and Petroleum Products (1st edition, Dec. 1994)
2. Manual of Petroleum Measurement Standards – Chapter 3 – Tank Gauging – Section 1B – Standard Practice for Level Measurement of Liquid Hydrocarbons in Stationary Tanks by Automatic Tank Gauging (2nd edition, June 2001)

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