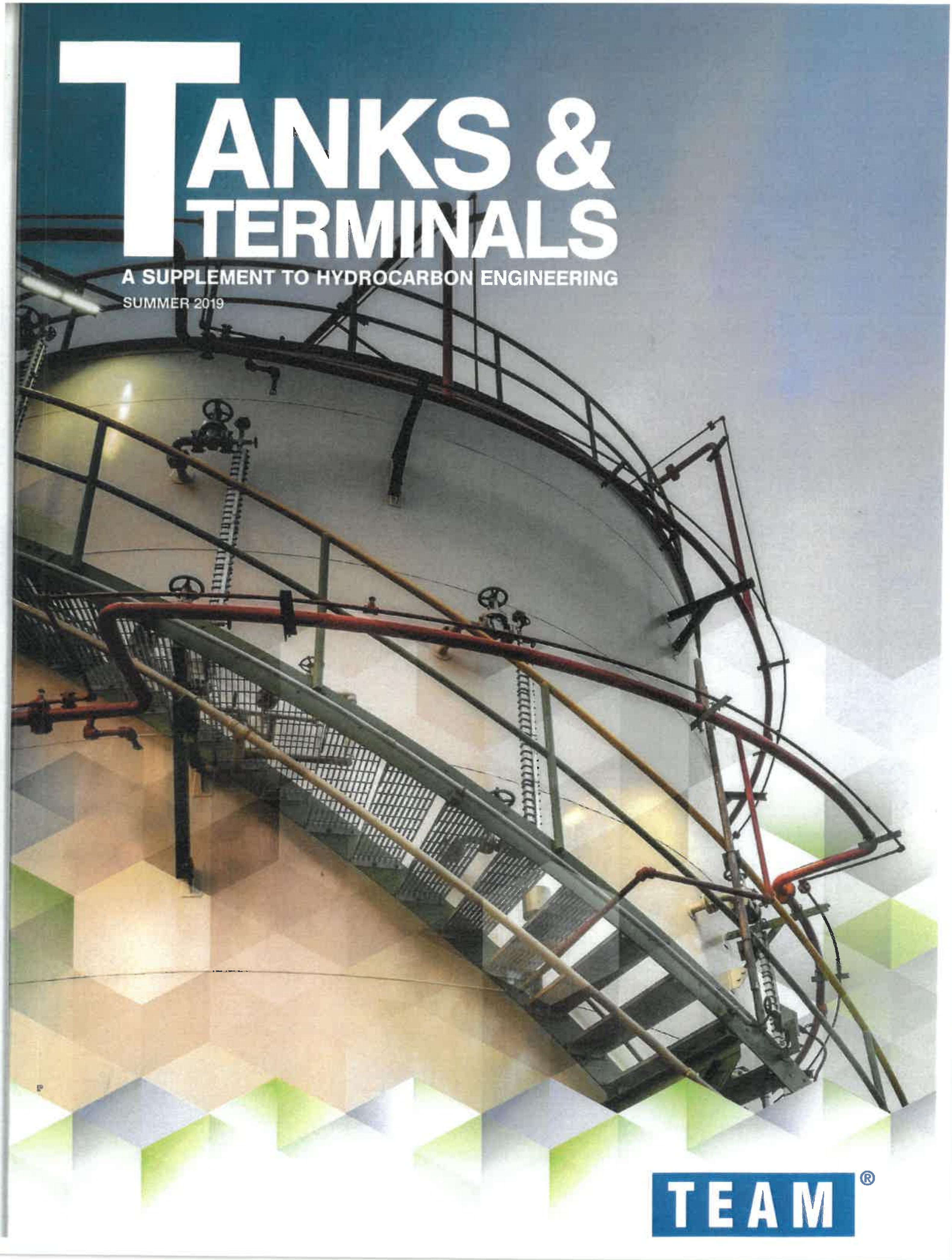
TANKS & TERMINALS

A SUPPLEMENT TO HYDROCARBON ENGINEERING
SUMMER 2019



MEASUREMENT OF WATER IN CRUDE STORAGE TANKS

Alexander Bukhman, Gauging Systems, USA, provides an overview of the measurement of water content in crude storage tanks with a modern multi-sensor hydrostatic gauge.

Bottom water measurement in storage tanks is a relatively easy task for light-end products because of well-defined water-oil interfaces. Traditional manual measurements or gauges based on float, magnetostrictive or bottom capacitance probes work relatively well within these products.

However, crude oil storage tanks present a significantly more complicated task for water content measurements. In most cases the interface is not well defined in such tanks due to a relatively wide emulsion layer.

There are significant problems with traditional methods of water measurement in crude storage tanks. Measurement tapes with water paste do not give an accurate result in emulsion layers. Electronic conductivity-based tapes are made for clear interface and will react unpredictably in emulsion layers depending on

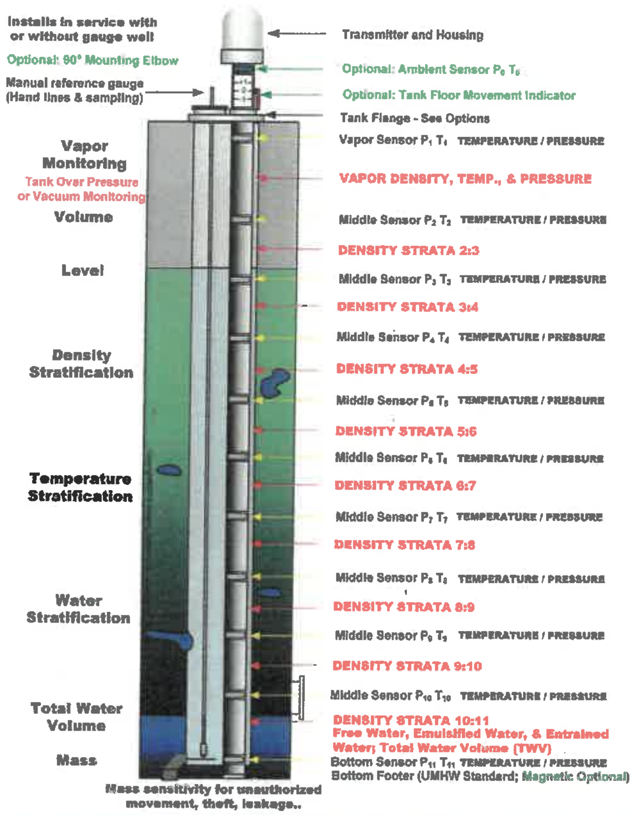


Figure 1. Modern multi-sensor hydrostatic gauge.

the emulsion composition and de-emulsifier chemical agents used.

Float gauges, magnetostrictive and capacitance probes are inaccurate in emulsified layers, and in crude storage tanks these layers can easily surpass the operating range of such gauges.

Accurate water content in crude oil tanks is just as necessary as accurate level and temperature measurements for custody transfer, inventory control, quality evaluation, and effective tank operation.

This article will examine through a real case study example, a solution to this problem through the introduction of a modern multi-sensor hydrostatic gauge.

Traditional and modern multi-sensor hydrostatic tank gauge (HTG) technology

Traditional hydrostatic technology was based on two to three pressure sensors mounted on the tank side.

While being a truly innage system, the traditional HTG had inherent problems that limited its application in practice, including:

- The mounting of transducers is outside of the tank.
- Hot tapping/multiple openings are required.
- Distance between pressure sensors is inaccurate and unstable.
- Pressure actuation point is unknown.
- Temperature gradient over pressure sensors.
- Wind effect.
- Reference movement.
- Density stratification causes level errors.
- Transducer re-calibration problem.
- No water measurements possible.

Modern technology

The modern multi-sensor HTG is based on a single probe with multiple pressure and temperature sensors embedded into its structure (Figure 1). The sensors measure absolute pressure with one or more reference sensors located either in atmosphere or vapour space of the tank or both.

While using the same physics of traditional hydrostatic measurements, the multi-sensor gauge eliminates the inherent shortcomings of traditional HTG. It provides more capabilities in terms of different measurements and a much higher accuracy than traditional hydrostatic technology.

The pressure and temperature measurements allow multiple results calculations, as shown below in simplified form:

- Density is calculated at each strata based on differential pressures and distances between the sensors, for example:

$$D_{34} = (P_4-P_3)/g/H_{43}$$

- Level is calculated based on the density of the uppermost strata, for example:

$$L = H_3 + (P_3-P_1)/g/D_{34}$$

- Mass above the bottom sensor is calculated utilising the tank strapping table:

$$M = (P_{11}-P_1) \times A/g$$

- Temperature readings are both multi-point and average.
- Volume can be derived in three ways:
  - Level and strapping table with temperature compensation.
  - Mass and measured density.
  - Mass and reference density.
- Water level and percentage of water in product are calculated by solving equations using the densities of the product and water.

Accuracy depends only on relative readings of liquid pressure vs vapour pressure, thus automatic calibration can be achieved with every tank movement when liquid sensors are exposed to the same vapour. The process is similar to weight tare calibration of a scale.

It is important to note that these calculations listed assume that P_1 is the vapour pressure under the tank roof as shown in Figure 1.

Unique functionality

The density profile provided by the modern multi-sensor hydrostatic gauge opens an opportunity to measure water content in highly emulsified crude oil tanks.

Since the gauge can measure density in the top layers of oil, which represent crude free of water, and in the middle/bottom density layers, where water can be present in emulsified form, then the percentage of water in these middle/bottom layers can be calculated without actually needing to measure the vague and undefined borderlines where water becomes emulsion and emulsion becomes product. The gauge can calculate where the oil/water interface will in fact occur when all of the water settles down from the crude.

The new approach provides the tank operators with a direct percentage (and total volume) of water in the tank, water distribution in layers with emulsified crude at any moment of time, and predicts the future in terms of where the settled water interface layer will be given enough time for all the water to settle.

Real case study

The following real case application provides an illustration of the capabilities of the multi-sensor hydrostatic system approach.

Application description

Three batteries of four 5000 m^3 (31 000 bbl) tanks are located in a remote area above 60° latitude (Figure 2). All tanks are over 12 m (40 ft) high. The batteries are a few miles away from each other, connected by a pipeline.

The first battery receives crude with high water content directly from the wells and works as a first stage separator. The outflow is regulated at approximately 5 m (16.5 ft) while the level in tanks is kept at approximately 7.5 m (24.5 ft). The tanks have constant feeding and simultaneous constant output. Demulsifiers are used to break down emulsion in an attempt to have only crude at the collection (outflow) level.

Routine measurements must be conducted in agitated tanks with dynamic process since stopping the tanks is usually not possible. Waiting for crude to settle is therefore not an option during regular operation. However, the operators constantly faced a problem of highly emulsified crude with emulsion layers reaching the outflow.

It is very important for the customer to understand how much water is in the tanks at each moment in time, as well as the water content at the output level.

The second battery is used as a buffer, while the third battery is used for custody transfer operations. Water content measurement is a priority on the first battery, while inventory control and custody transfer measurements (including not only water content, but also level, volume, density, temperature and mass) are important in the second and third batteries.

The site operators used different methods to evaluate water content in these tanks with very unreliable results.

Manual measurements using an electronic water tape based on a conductivity principle were very unstable in the usual dynamic situation of tank operations and varied greatly when any settling time was allowed.

Manual gauging with water paste did not prove satisfactory either.

Attempts were made to obtain the water/emulsion/crude layers using a portable densitometer based on a resonance sensor with an electronic readout, but results proved very unstable in emulsified product.

Manual measurements could not serve as a solution for process requirements and any attempt to use float/displacer/microwave instrumentation failed due to the various degrees of water and emulsion present over most of the liquid height in the tanks.

Finally, a multi-sensor hydrostatic system was installed on all three batteries providing a successful solution for each of the tasks, but this article will only consider the results of application in the first battery of tanks.

The installed gauges were able to calculate and transmit to the operators via MODBUS the following parameters:

- Diagnostic data.
- Level.
- Water settled level – equal to the predicted level of total water after full settling.
- 12 temperatures – 8 from liquid as only 8 sensors were covered, and 4 from vapour space.
- Densities of 7 covered layers – observed and converted to standard temperature.
- Percentage of water in layers – 7 values for layers between 8 covered sensors.
- Percentage of water above each sensors (sensors are located every 1 m or 3.28 ft).
- Average temperature of liquid.
- Density of product.
- Volume (TOV, GOV, GSV, water volume).
- Calculated low and high ends of the emulsion.
- Mass of liquid and product/water in tank.
- Volumetric and mass flow.

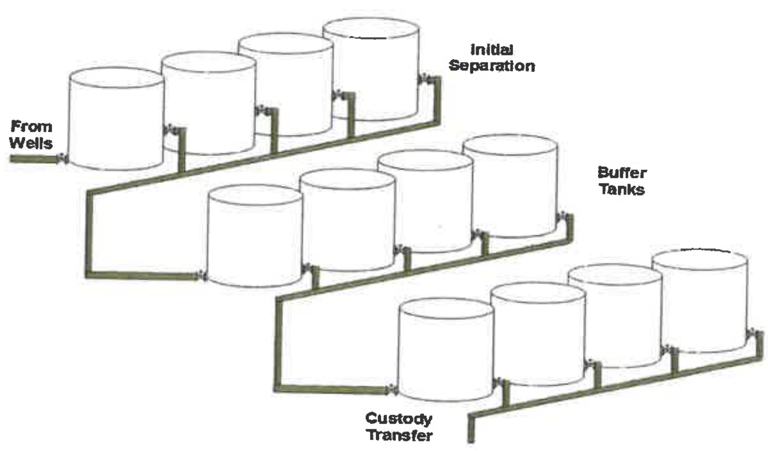


Figure 2. Crude oil and water separation site.

Table 1. Test results

Local time	Electronic tape D2401-2 (№XXX85) (mm)		Time	Electronic tape D2401-2 (№XXX12) (mm)		Time	Multi-sensor hydrostatic gauge level measurements (mm)			
	Top liquid level	Interface level		Top liquid level	Interface level		Level from the gauge	Settled water level predicted from the gauge	Estimated top of emulsion from the gauge	Estimated bottom of emulsion from the gauge
04:11	Tank stopped									
04:12	7436	2096	04:14	7436	2016	04:14	7436	3397	4512	2632
04:54	7431	3006	04:56	7426	2981	04:56	7429	3377	3936	2824
05:32	7416	3196	05:34	7416	3236	05:34	7423	3373	3923	2894
06:06	7416	3426	06:07	7416	3376	06:07	7418	3376	3912	2930
06:39	7406	3436	06:42	7406	3431	06:42	7411	3376	3908	2948
07:12	7406	3496	07:14	7406	3476	07:14	7407	3372	3904	2956
07:41	7406	3501	07:42	7406	3481	07:42	7404	3376	3902	2968
08:45	7396	3496	08:48	7396	3486	08:48	7394	3372	3897	2985

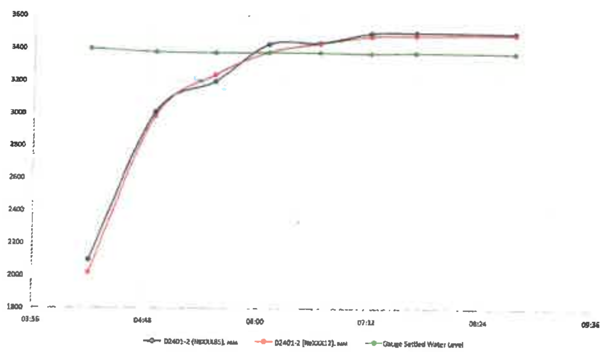


Figure 3. Interface reading consistency – tape vs gauge.

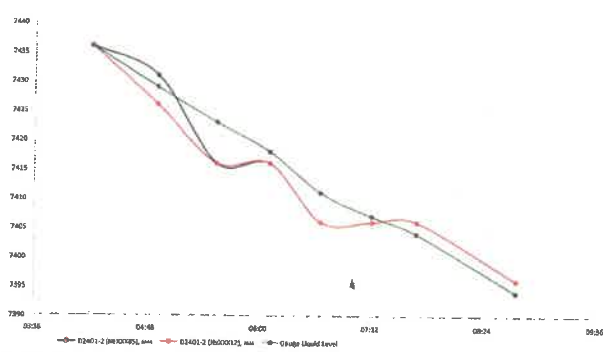


Figure 4. Liquid level tapes vs gauge.

Table 2. Gauge readings of layer density and percentage of water in layers at 03:51:47 on 26 February 2018

Layer borders (mm)	Density kg/m³ at 15°C	Water percentage (%)	Time
7200 – 8200	Layer is not filled	0.0	03:51
6200 – 7200	848.6	0.00	
5200 – 6200	853.3	3.29	
4200 – 5200	859.5	7.56	
3200 – 4200	912.6	41.85	
2200 – 3200	978.3	79.11	
1200 – 2200	1017.4	99.61	
200 – 1200	1017.6	99.45	

Test procedure

Operations stopped each tank and allowed them to settle for 4 – 5 hrs.

Measurements were taken by two electronic tapes for overall level and water level before the dynamic process was interrupted and then approximately every 20 min. after tank stoppage during tank settling.

At the end of the settling process, electronic densitometer readings were taken as well as manual tape readings with water paste.

The data log from the multi-sensor hydrostatic gauge was recorded every 3 min. for all periods of the manual measurements. The results are shown in Table 1.

Interface readings from electronic tapes changed by over 1.4 m (or over 4.5 ft) while the predicted settled water level readings by the gauge were within ±0.5 in. during the entire period of time from tank stoppage to the end of 4 – 5 hrs of settling. At the same time, the total liquid level readings were very close between the gauge and the electronic tapes at all time (Figures 3 and 4).

The most interesting results are the percentages of water in each layer. The readings present a virtual window into the tanks' settling process at any given moment of time. Tables 2 and 3 show the water distribution in emulsified layers before the settling process began and just before the testing period ended.

One can see how the top layer density did not change, while the density and water content of the next two layers dropped slightly during the settling time. The middle layer's water percentage dropped to 30.39% and the water content of the next layer towards the bottom increased from 79.11 to 91.45% – almost all water. The bottom two layers are obviously free water throughout the process.

The continuous settling process can always be monitored and recorded as shown in Figure 5 based on real gauge readings.

Finally, a portable densitometer and tape with water paste were used to verify the gauge data at the end of the test. It must be noted, however, that neither a portable densitometer based on resonant sensor, nor a tape with a water paste could provide reliable results in

Table 3. Gauge readings of layer density and percentage of water in layers at 09:07:00 on 26 February 2018

Layer borders (mm)	Density kg/m³ at 15°C	Water percentage (%)	Time
7200 – 8200	Layer is not filled	0.00	09:07
6200 – 7200	848.6	0.00	
5200 – 6200	852.3	2.83	
4200 – 5200	852.5	2.45	
3200 – 4200	894.2	30.39	
2200 – 3200	1002.3	91.45	
1200 – 2200	1017.2	99.46	
200 – 1200	1017.4	99.43	

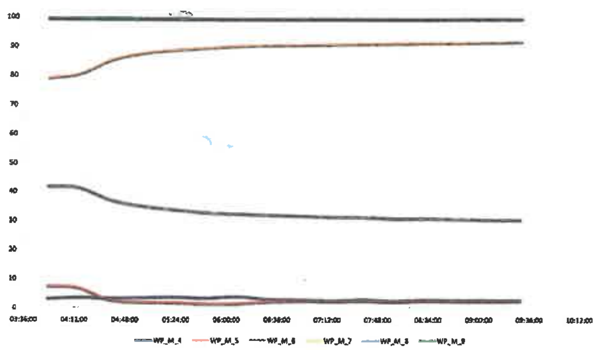


Figure 5. Change of water percentage distribution in layers with time.

emulsion, which was not completely settled even at the end of the test.

Manual tape readings with water paste taken at 09:30 local time showed the most colour change between 3300 and 3500 mm with no clear cut – very close to the settled water level predicted by the gauge.

The densitometer had a sharp change in readings from water to oil around the same area.

Both methods provide a qualitative representation of water/oil interface and both confirmed the gauge readings.

Similar tests were performed on all tanks of battery 1 with virtually identical results.

Conclusion

The modern multi-sensor hydrostatic gauge can provide an accurate picture of water distribution in layers with emulsion and suspended water over the entire volume within crude storage tanks. Total percentage of water, water distribution throughout the liquid height in a tank, and even predicted settled water level are now available with a high degree of metrological reliability.

The multi-sensor hydrostatic gauge allows optimisation of processes involving de-emulsifiers and water settling with real time monitoring.

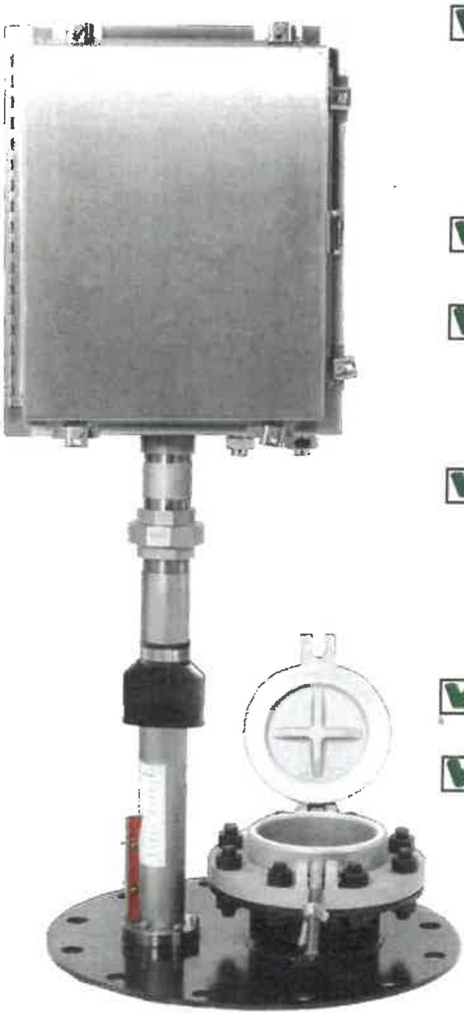
The technology provides a full set of quantity and quality measurements of liquid in a tank with one single instrument installation, including level, water content, density, temperature and even pressure and temperature under the roof and accurate total mass – allowing for emissions monitoring and leak detection. T&T

Does your Automatic Tank Gauge meet your current and future needs?

(Loss Control - Saftey - Environmental - Operational)

MTG "Multi-function Tank Gauge" does!

MTG



- **Volume Measurement to Custody Transfer Accuracy**
  (API 16.2 and/or API 3.6)

- **Quality Measurement** - Product (Fuel) (API 1640 and 1543)
  Product Stratification (Multi-point Temperature, Multi-strata Density & Water) Automatic Sampling (Based on API 8.1, Upper-Middle-Lower)

- **Overfill Protection** (API 2350)

- **Rupture Protection** (Tank Over Pressure & Tank Vacuum)
  Pressure Relief Vent Monitoring
  Gas Blanket Monitoring

- Unauthorized Product Movement
  Leak Detection (Mass Sensitivity)
  Improper Line-ups (Product Contamination)
  Theft

- **Vapor Emissions Monitoring** (Measured Parameters)

- Provides: Volume, Mass, Level, Multi-point spot temperature, Average temperature, Multi-strata density, Average density, Total water (Free, Emulsified & Entrained), Vapor (Pressure, Temperature & Density), Ambient (Pressure, Temperature & Density), Flow rate (Volume & Mass), and Tank Bottom / Roof Movement Indicator.

- One tank entry, with or without gauge well.
  Allows for direct calibration at the same physical reference point between ATG and manual hand-lines.
  Self-Calibrating and Self-Diagnostic.
  Certified I.S. Instrument. (ATEX, GOST, IECEx, UL)