

## Improving Temperature Measurement to Optimize Inventory Control and Custody Transfer Systems

The measurement of temperature is critical in the determination of the true volume of product in a hydrocarbon storage tank and how that may be improved with the use of true averaging sensors or multiple-spot temperature sensors. Simple temperature measurement has been performed for many years, in ways as simple as glass thermometers hung in a tank or as sophisticated as a tank gauging system mounted on the tank roof.

Temperature has the most significant effect on the accurate determination of liquid quantities when correcting to standard conditions for custody transfer and inventory control purposes. “An error in the determination of temperature may result in either over-or understatement of the quantity, regardless of the accuracy obtained in gauging the liquid’s level”.

The accurate measurement of temperature is a critical factor in determining the volume of the contents of a tank and the transfer of the material out of the tank. “A change of 1 deg. F in the product temperature can allow an error of 120 barrels, in a tank of approximately 300,000 barrels”. At the current price of petroleum, an error of that magnitude could be significant. In the past, a single thermometer inserted into the tanks was sufficient for monitoring the temperature of the tank. Now, that method is decidedly not sufficient according to new standards from the American Petroleum Institute. Oil tends to stratify as it settles in the tank, which is compounded as product is moved in and out the tank. Because of this phenomenon, a more reliable means of measuring the temperature in the tank is required. The only way to get the correct reading of the actual temperature in the tank is to use an averaging temperature sensor. Use of this device will allow temperature measurements to be taken at various heights in the tank, thereby negating the effects of product stratification.

“For custody transfer temperature measurement, local direct-reading thermometers are not recommended. Copper or platinum temperature elements bulbs, that is resistance temperature detectors (RTDs) are normally used for this application.” Choice of the method of temperature measurement, e.g. single-point, multiple-point or averaging, should be based on the desired accuracy requirements and the type of material in the storage tank. (See photos A & B).

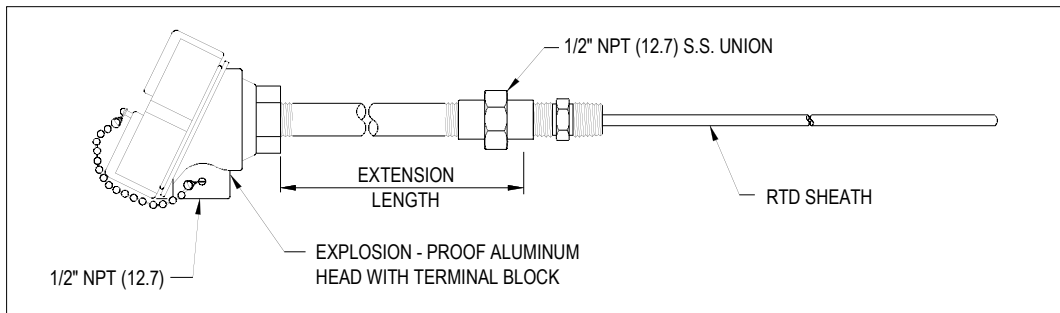
Photo A - Type G Single Point RTD



Photo B – Type MA & MS Averaging Temperature & Multiple Spot RTD



Fig. 1 – Type G RTD Assembly with Nipple-Union Extension



The first type of temperature sensor, other than direct-reading thermometers, would be a single—point RTD (see fig. 1). Copper or platinum electrical-resistance RTDs are normally used for custody transfer temperature measurement because of their high accuracy and stability. These RTDs, nominally 36" (900mm) long are screwed into stainless-steel thermowells that are mounted through the tank shell at a height above the tank bottom of at least 36" (900mm) (see fig. 2). This type of sensor is usually installed near an access or gauging hatch. They feature high accuracy and insulation resistance strength. The sensor element should be encapsulated in a fill material to provide ruggedness and fast response time. This type of sensor can be either a 3 or 4 wire RTD, which will provide full lead-wire compensation. The sensors are usually constructed of stainless steel tubing to provide the long-life required by the storage tank industry.

An option to the single-point RTD in metal tubing is installation of the RTD elements in a flexible, stainless steel or Monel hose, which is flange-mounted to the tank roof (see fig. 3). This type of sensor provides a convenient and economical means of installing a temperature sensor in a tank in service without hot-tapping the tank shell to accommodate a thermowell. It is designed for direct immersion in the product. The spot sensing element can be either 100-ohm copper or 100-ohm platinum and is not to be longer than 4" (100mm).

Fig. 2 – Type W Thermowell with Flanged Tank Connection

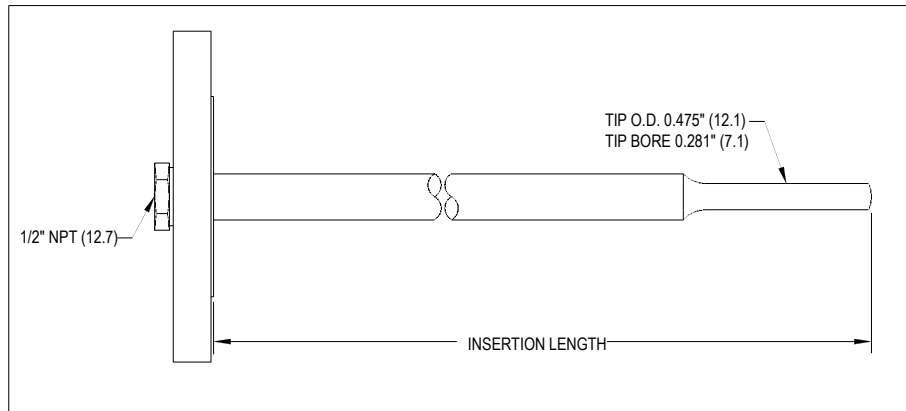
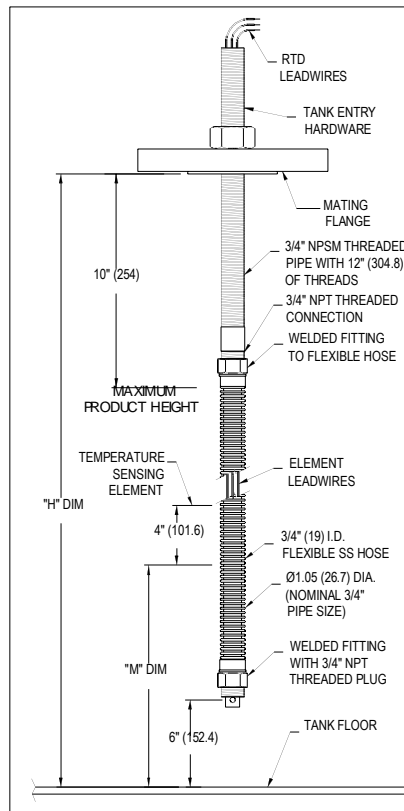


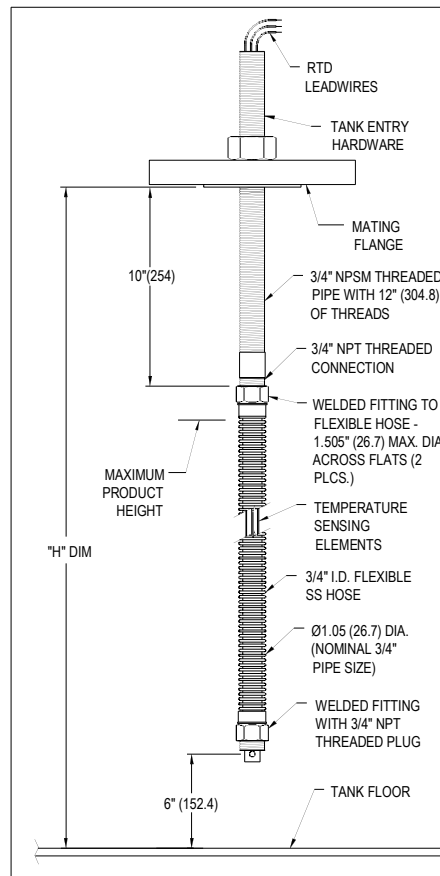
Fig. 3 – Type R RTD



The above sensors are two of the more common and least-cost ways of measuring the temperature of the product in the tank, Now, a way to measure the temperature that will give you increased accuracy and dependability. Averaging temperature RTDs provide a

convenient, accurate, permanently installed primary sensor for the determination of average temperature in a large storage vessel (see fig. 4).

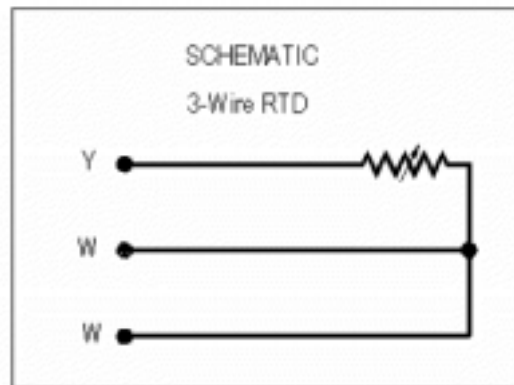
Fig. 4 – Type MA & MS RTD



Per the American Petroleum Institute, Manual of Petroleum Measurement Standards, Chapter 7-Temperature Determination, a tank at least 50' tall would require a minimum of ten (10)-averaging sensors. As the tank height is reduced, less averaging sensors are required. The prescribed lengths are 3', 5', 7', 10', 14', 20', 26', 32', 40' and 50' (see fig. 5). Rarely, a taller tank is encountered and a 60' and 70' averaging sensors can be provided. This temperature sensor, or multiple element temperature averaging RTD, consists of an array of sensing elements of varying lengths, as mentioned above, which are temperature sensitive over the entire length and which all extend to the bottom of the tank. The average temperature is determined by selecting the longest fully submerged element and connecting it into the temperature measuring circuit, which could be the switch in the ATG or by software in the ATG system. The elements can be either 100 ohm copper or 100 ohm DIN platinum-characterized copper. This type of sensor is housed in a flexible, annular-ring, stainless-steel or Monel hose, which is commonly mounted to a mating flange that bolts to the existing tank nozzle and is held

vertical in the tank product with an anchor weight of approximately 25 lbs. If turbulence or stirring is occurring in the tank, whereby the anchor would not keep the sensor stable, then an alternate positioning technique would be to install the temperature sensor in a perforated, stilling pipe. This is a pipe with holes along the axis, secured at the top of the tank and bottom of the tank, that allows the product in flow in and around the temperature sensor, thereby giving an accurate temperature measurement of the product.

Fig. 5

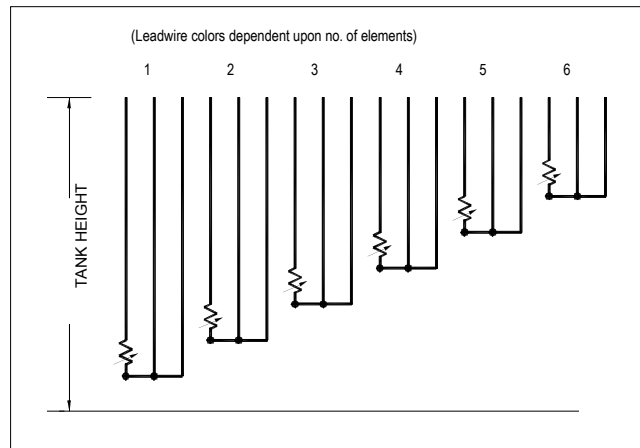


At times, due to the product type or temperature rating, the sensor cannot be placed directly in the product, but must be installed in a stilling well. This stilling well is similar to the one above but with no holes and is also attached to the tank roof but has the bottom end closed off. Mineral oil, or similar weight material, is then poured into the well and the sensor temperature installed into the well. The temperature of the tank product is then transferred to the temperature sensor through the mineral oil, thus keeping the sensor from directly touching the product. This application is most appropriate when the temperature of asphalt or similar type of material is measured.

A second means of determining the average temperature of the tank product, per the API, is with multiple-spot, RTD temperature elements (see fig. 6). “Multiple spot temperature elements are installed at approximately 3 meter (10’) intervals with the lowest element approximately 1 meter (3’) from the bottom of the tank”. As an example, a 30’ tank would require 4 elements; a 30’ to 50’ tank would require 5 elements and a tank greater than 50’ would require 6 spot elements. In this configuration, all of the submerged elements are measured and arithmetically averaged with system software to arrive at the average temperature of the material in the tank. Though the API recommends a minimum number of elements, no maximum is stated. Having additional elements at closer intervals could provide an even more accurate determination of the product temperature. This is particularly true in Thermal Energy Storage Tanks. These are tanks of water used for cooling in very large buildings. Thermal stratification has to be more finely monitored with more elements due to the lower temperatures

experienced with thermal energy storage. A second benefit of the multiple spot system is the ability to use the spots to provide the vertical profile of the temperature. The spot elements can be either 100-ohm copper or 100 ohm DIN platinum, depending on the ATG used. One additional benefit of multiple spot elements is that the ullage temperature in the tank, if required, can also be measured with one of the spot elements not in the product. This would allow the temperature of the vapor space to be known, if required.

Fig. 6 – Schematic – Multiple Spot Elements



A third means of measuring the average temperature in the tank, per the API, is with a multiple spot, thermocouple system. Each thermocouple, like the multiple spot RTD element, measures the product temperature at a specific point. A thermocouple array will usually have at least 15, evenly spaced spots. An average temperature of the product is made by arithmetically averaging all the spots submerged by the product. Additionally, individual spots can be used to determine a tank temperature profile. A 100-ohm, platinum RTD is usually installed in the tip of the hose as a reference point for the lowest point of temperature measurement in the tank. Individual spots not immersed in the product can be used to measure the ullage temperature of the tank. Knowing the temperature of the vapor space can be useful information, if required. Though copper or platinum RTDs are normally used for custody transfer, thermocouple assemblies are gaining acceptance. Though it would be preferable to design the temperature sensors into the initial tank design, all of the above type of sensors can be added to the tank either before, during or after construction of the tank. Due to the fact that the averaging sensor is installed through a single nozzle on the tank roof, maintenance is very easy. If a sensor should need to be replaced, the flange is unbolted and the sensor is lifted straight out of the tank (see fig. 7 and fig. 8).

Fig. 7 – Existing Nozzle Installation  
with Type O Tank Entry Fittings

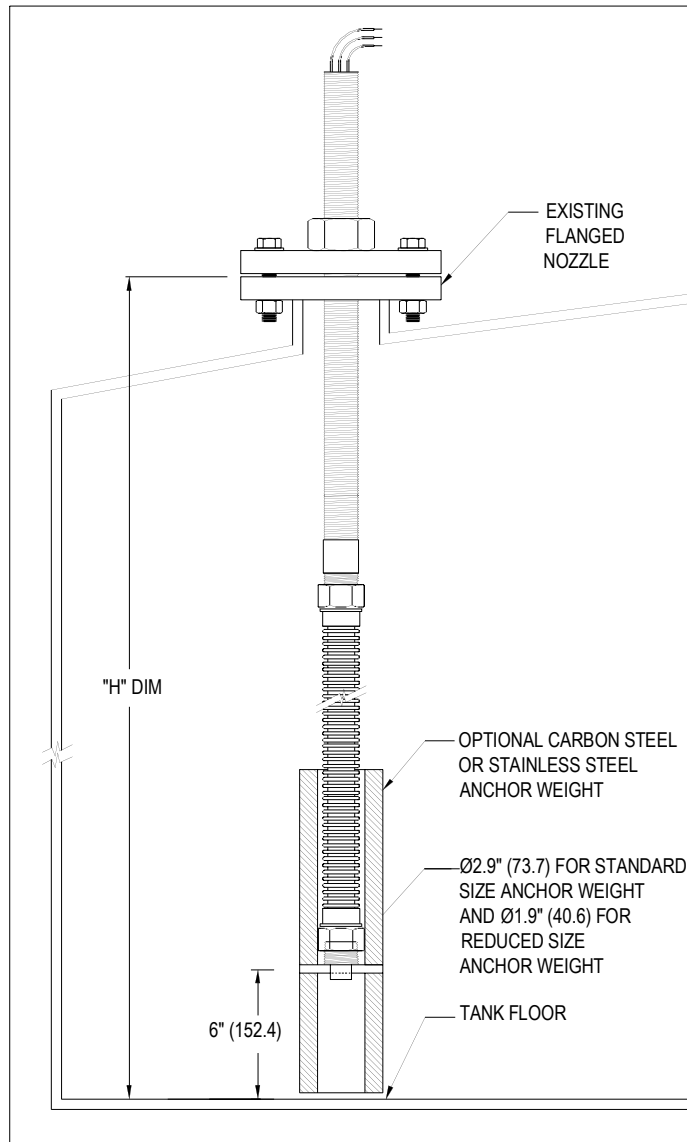
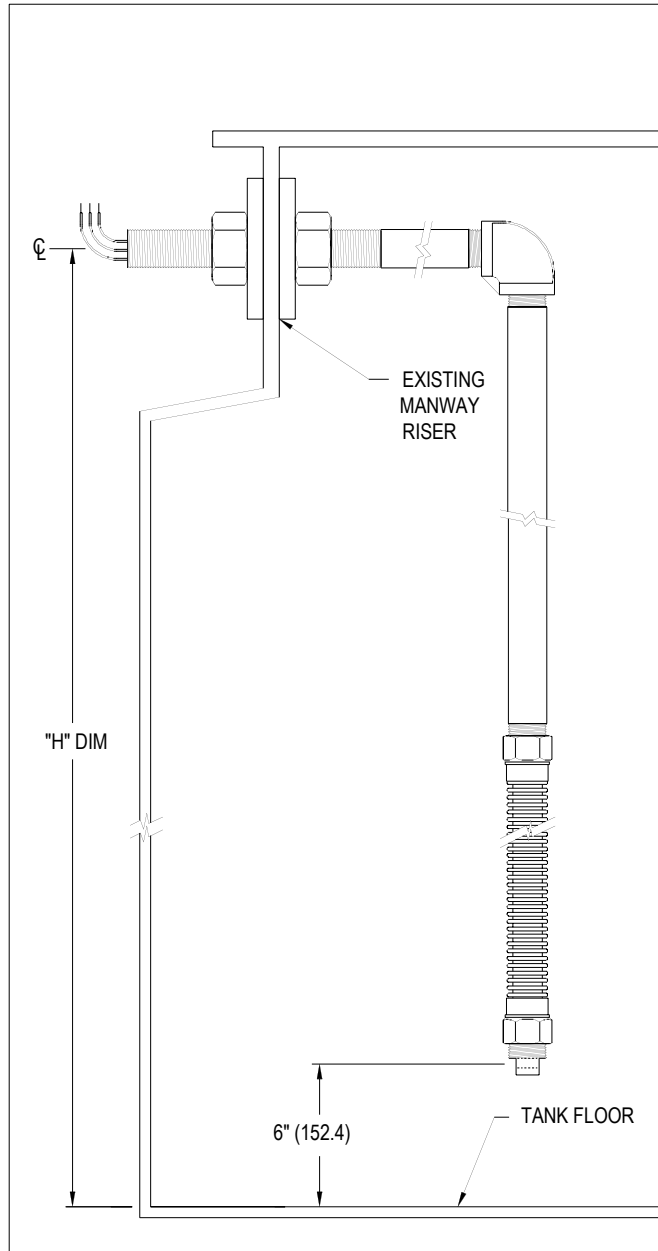


Fig. 8 – Vertical Surface Entry Installation  
With Type 6 Tank Entry Fittings



## Advantages and disadvantages of different temperature measurement equipment

### Averaging RTDs versus spot RTDs versus Thermocouples

- Averaging RTDs provide a more accurate means of measuring the average temperature in an oil storage tank than any other means
- Obtaining a tank temperature profile of the product in the tank can more accurately be determined with a spot temperature array
- The individual spot temperature elements have the ability to give a discrete point of temperature measurement in the product
- Spot temperature sensors can give a point of measurement in the ullage of the tank
- Each spot measurement is an individual 3 or 4-wire RTD
- Average temperature elements have a common ground
- Averaging elements extend to the bottom of the tank
- Multiple spot elements begin at the top of the tank
- Averaging RTDs negate the effect of thermal stratification
- Multiple spot RTD can produce a tank temperature profile
- The tank gauging system selects the longest, fully submerged averaging element to determine the average temperature
- All submerged spot elements are measured and arithmetically averaged to determine average temperature
- RTDs are repeatable and stable and are the primary interpolation instrument used by the NIST, (National Institute of Standards and Technology) additionally drift is typically less than 0.1 °C/year
- The voltage drop across an RTD provides a much larger output than a thermocouple
- Copper and platinum RTDs produce a more linear response than thermocouples
- Thermocouples can withstand higher temperatures than RTDs, as high as 1800 °C
- Thermocouples are simpler devices than RTDs, which makes them inherently more resistant to shock and vibration
- Thermocouples have a faster time response and lower mass than RTDs

## New developments

### Water Bottom Monitor

In addition to providing a highly accurate and dependable average temperature of the tank contents, the Combination Averaging Temperature RTD and Water Bottom Monitor also provides a continuous indication of water/oil interface (see fig. 9). This information can then be factored into the net barrel calculation along with temperature correction. Additionally, the information can be utilized to schedule water draw-off activities. The water interface-measuring portion of the assembly utilizes a capacitance probe with intrinsically safe circuitry to determine the interface level between the water and product in the tank. The transmitter is microprocessor-based and can be supplied with a 4 to 20 mA or HART output. The Water Bottom Monitor may also be supplied without temperature sensing elements, if all that is required is to indicate the oil/water interface. (See photo C).

Fig. 9 – Type MWR

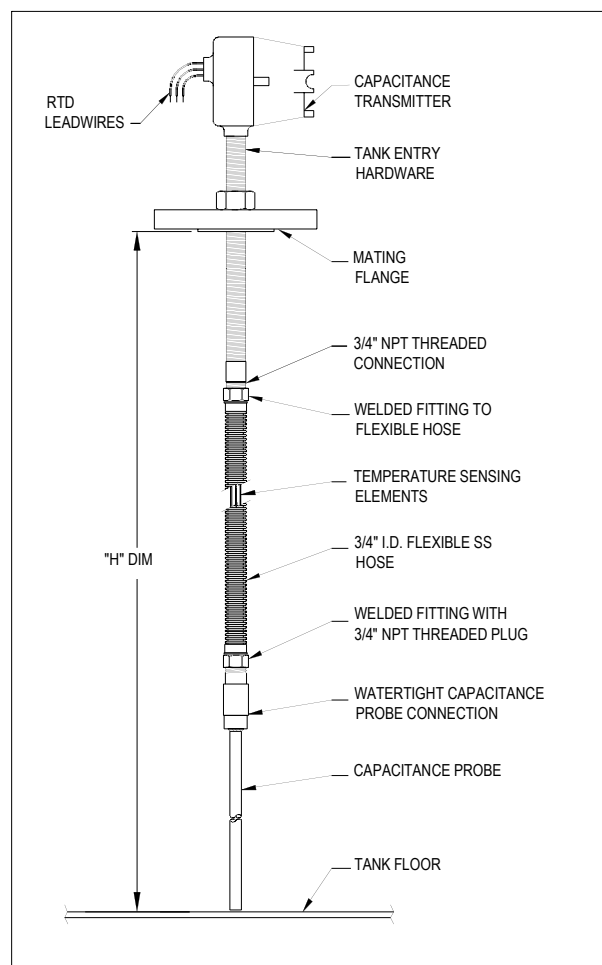


Photo C – Capacitance Probe with Transmitter



### Plug-and-Play

Plug and play for self-identification of various sensors. Joint effort with National Instruments. Compliance with the recently introduced IEEE1451.4 standard for plug-and-play compatibility will digitally describe and identify each discrete sensor by means of a TEDS (Transducer Electronic Data Sheet) written on an EEPROM, which resides with the sensor. This offers added security in testing, providing manufacturer and user information that is unique and permanently affixed to the sensor. The correct sensor is always correctly identified and calibrated, thus increasing confidence and reliability in system validation. (See photo D for type of sensor that could have optional TEDS).

Photo D – RTD Assembly with TEDS Option



The question has been asked about other uses to which this type of technology could be applied. We submit that this type of sensor can be used in any type of liquid, as long as it is compatible with stainless steel or Monel. We have supplied multiple-spot averaging sensors to very disparate applications, such as a high-purity, liquid sodium storage for Dow Chemical and wine fermentation tank for Gallo Winery.

### [Thermal Energy Storage \(TES\)](#)

Another area of growth outside the petroleum-based storage tanks is Thermal Energy Storage (see photo E). TES tanks are chilled tanks of water, used for cooling in large buildings. Stratification is a real problem in these tanks, since cold water is being drawn off the bottom of the tank and warm water is being dumped into the top of the tank, as the water is used during the day. The tank operator needs to know where the thermocline (the boundary between warm and cold water) is located in the tank, so that the amount of energy to cool-down the tank at night is known. Two applications manufactured recently are for a 65' and 90' tall tank. Each of these tanks had one multiple-spot element array, with the elements on a 2' spacing. The 65' tall TES tank had 32 spot elements and the 90' tall tank had 45 spot elements. The tank in photo A is the 65' tall tank and is located in Orlando, FL. It is the world's largest TES tank, holding about 17 million gallons of water in a tank 223' in diameter.

Photo E – Inside Thermal Energy Storage Tank



## Conclusion

Temperature can be measured in many ways, with many different types of devices. For most of our customer's applications, we submit that the best way to measure the average temperature is with an averaging temperature or multiple-spot type sensor array. This will give you the most reliable and consistent measurement of the average temperature in the tank.

Weed Instrument can serve your temperature measuring opportunities with a complete line of sensors: whether your needs are for single-spot measurement, multiple-spot measurement or water/oil interface detection. (See photo F).

Photo F – Suite of Tank Gauging Products



## References:

“Tank Temperature Measurement Using Averaging Techniques”, John Pritchard, 1994

“Manual of Petroleum Measurement Standards”, Chapter 7 – Temperature Determination, June 2001

“Manual of Petroleum Measurement Standards, Chapter 3-Tank Gauging, Dec. 1994

Weed Instrument Tank Temperature Measurement catalog