Challenging abilities for tank monitoring by means of submersible density/temperature meters

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Companies involved in the oil industry or trading petroleum products face difficulties every day, one of which is oil weight calculation.

The solution to these problems often relies on "know how" companies, specialized in liquid products weight calculations in terminal storages, tankers, railway and auto-tanks.

Oil products in most cases are liquid, therefore, measured in liters, but commercial oil product operations are measuring in kilograms.

There are many different ways to find a precise weight of liquid oil products.

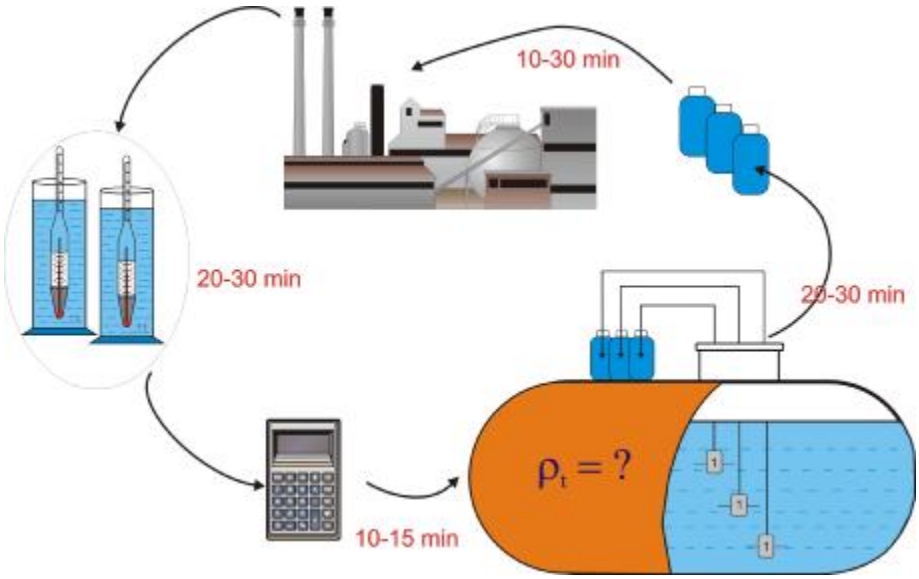
One of the most popular methods is the volumetric-mass method, when the weight of oil product is calculated by the following formula:

$$M=V \times \rho$$

To determine weight we need to know 3 parameters – volume, density and temperature. The main "stumbling block" in this process is to measure the above parameters simultaneously.

To calculate a volume with high precision, it is necessary, first of all, to find the level of liquid in the tank, then, having a calibration tank table, and knowing the precise level of liquid, finds the volume of liquid in the tank at present time.

The second parameter, which is necessary to determine – is the density of liquid in the tank at present time, on several levels. The third parameter is the temperature of the liquid in the tank at present time, on several levels. We state "at present time" because it is necessary to determine all three parameters simultaneously or almost simultaneously, otherwise after some period of time (depends on outside factors) all three measurements will change. For example air temperature can increase, or the sun will heat a tank and the three parameters will change in the following way: temperature increase – density decrease and thereafter volume of the oil product in the tank will increase.



Picture 1. Standard procedure of density measurements

Using a standard method to determine density usually involves taking a sample of liquid from three different levels (surface, middle and bottom). The temperature of the sample is measured immediately after the sample is taken (or there should be a temperature measurement taken at three different depths or at the same time as the level measurements). But what is the guarantee that the temperature and level measurements have been taken from the exact same place – or that the samples have been mixed thus rendering the temperature measurements void? Naturally, taking a sample and immediately measuring its temperature is far more accurate than in the above scenario, but this is subject to there being no exogenous metrological factors such as wind, precipitation and sun. Should this occur the temperature reading should be very accurate (within 0.3 – 0.5°C), but with adverse weather factors accuracy will be diminished.

After receiving the temperature data, samples are delivered to the laboratory, where, using different laboratory instruments (glass hydrometers, stationary laboratory density meters, pycnometer and etc.), a medium value of the received samples is found and the density recalculated at 15-20°C (depending on the national standard).

To determine density of the oil products in big tanks, it is recommended to take not 3, but a minimum of 5 samples for finding much more precise results of density (1 sample from the surface, 1 from the bottom and 3 from the middle).

On the face of it, every step of this process seems easy; take the sample, send it to the lab, measure its density and calculate the result. But it is known, that there are many outside factors that can affect each sample, such as: temperature inside the tank, ambient temperature, evaporation of sample, bleeding of gases, contact with the air (oxidation), etc.

1.When sample limits the precision of the density measurements.

Even a superficial view of the Standard Methods of density measurement reveals some problems.

Some of the most popular Standard Methods of density measuring are listed in Table 1. (Standard methods using pycnometers are not included in this revue.)

Table № 1.

Standard Methods of Density Measurements

Standard Method	Measurement technology	Repeatability kg/m^3	Reproducibility kg/m^3	Bias kg/m^3
ASTM D1298	Hydrometer • Transparent • Opaque liquids	 0.5 0.6	 0.12 0.15	 Not determined
EN ISO 3675-98	Hydrometer	The same	The same	Not determined
ASTM D4052	Digital U-type resonator	0.1	0.5	0.6
EN ISO 3675-98	Digital U-type resonator	0.1	0.5	0.6
ASTM D5002 For crude oil only.	Digital U-type resonator	0.9 (for 850 kg/m3)	3.6 (for 850 kg/m3)	0.6

The resonant method can move this point up to 0.01 kg/m3. But this result is only for ideal liquids, such as distilled water. Sample characteristics, usually encountered in practice, are far removed from such ideal objects of measurement. Air saturated samples, evolving of light volatile components (gasoline Heterogeneity and non-homogeneity (crude oil), highly viscous products (black oil) are far more common samples.

Problems with these measurements have lead to the development of ASTM Standard Method D 5002 for heterogeneous liquid (crude oil), where repeatability is 9 times worse comparing with ASTM D 4052. The permissible margin of error of oil density measurement on ASTM D 4052 may not always be achievable, for instance if a sample undergoes a physical process under the laboratory's conditions (i.e. temperature) this will severely hamper accurate density measurement.

The hydrometer is also not free from extraneous influences. A possible additional error is air bubbles, water or paraffin sticking to the hydrometer walls, and also electrostatic effects in the hydro carbonic environment. Such "difficult" samples for which it is problematic to receive exact results are well known to the experts. Therefore statements, which maintain, that an error of hydrometer measurement depends only on correctness of its (hydrometer) graduation and the accuracy of the thermometer (ASTM D 1298) are disputable. It is marked in EN ISO 3675-98 method: for oil and other "difficult" objects accuracy parameters from the Table1 can be unattainable. The same can be said for easy, non-stable and non-homogeneous liquids.

It is no exaggeration to state that real objects of measurement limit density measurement accuracy. No matter how far progress on improvements of the U-shaped resonator or other laboratory density meters is made, the real error will be defined by

the character of interaction of a non-ideal sample with a sensor control, instead of technical advancements. Everything mentioned above, concerns the laboratory practice of measurements.

2.The error of the laboratory measuring methods is not a basic factor of weight measurement errors in tanks.

Conditions of measurement in a laboratory can be named "controllable". Conditions of measurements " in the field ": on the tank, on a railway platform, on a gasoline tank truck do not relate in any way to them. They can be called "measurements in uncontrollable conditions", and frequently in "extreme conditions". There is a high probability that the sample's temperature measurement result in the laboratory and the same sample - on the roof of the tank (in wind, under rain, in frost) will considerably differ. The error of measurements " in the field " is much higher, than in laboratory, and it inevitably affects the estimation of weight of a product in the tank.

All this makes measurement of density " in the field " by laboratory devices (hydrometer or digital density meter) problematic. The practice of sampling and its (sample) carrying to a laboratory's controllable conditions of measurement is accepted. Usually, it is a far and long way without a guarantee of preservation of properties of the test.

None of the techniques listed above give even rough estimates of the distortions, connected with sample carrying. This data is outside of the laboratory's responsibility. At the same time it is problematic to maintain a representation of oil or easy gasoline samples during transportation to the laboratory. Such liquids can change their properties and density. It would be perfect to carry out measurements on site.

3. Sample representation

The other problem that occurs during measuring the weight of a liquid in tanks is representation of samples. Precise measurements in a laboratory will be useless if the mix in the sampler does not correspond to the average structure of the liquid in the tank.

This problem is especially prevalent for big tanks during cold and hot seasons because of the inherent layerwise demixing of the liquid (by its density and temperature) along the height of the tank. This occurs more often in high-octane gasoline with additives and in crude oil.

In a cold season the oil in tanks can look like "a puff pie" with layers of different density and water content in it. In such cases the representation of the samples becomes a priority problem for liquid product weight evaluation.

The routine procedure of sampling from three levels: upper, middle and lower (in accordance with ASTM D4057 and ISO 3170) and temperature detection in each of these samples will give an adequate result only in the case of a homogeneous or

proportional distribution of density and temperatures along the height of the tank. Sometimes more representative samples can be obtained by the "running" method, but such way of sampling requires a highly skilled operator.

The dilemma is: On one hand; the shorter the spacing between neighboring samples; the more accurate the measurement of density and temperature obtained. But on the other hand; the more thorough the sampling procedure, the more time consuming and costly it is.

As a rule, nobody publishes the estimate of deviation, which was made calculating the weight due to non-representation of the samples. Such deviation and methods of its calculation are the intellectual capital of the surveyor companies, which are engaged in goods' weight evaluation. In practice, the calculated correction may significantly exceed the error originated during density measurements in laboratory.

Here is a problem: the laboratory is responsible for the correct density measurement of the sample after its arrival, but not for the whole succession of procedures: sampling – sample transportation – measuring. However, tank farm owners or surveyor companies are interested in error minimization at every phase of the analytical succession, because the total error brings a discrepancy in weight evaluation (during acceptance operations) and as a result – to financial losses for the company.

The monitoring of density and temperature in the tank is therefore the most efficient solution.

The usual sampling procedure (taking several samples along the full height of the tank) is very expensive and labor consuming. Using submersible density/temperature meters means that the operator can take accurate density/temperature measurements on site, without the need for sampling.

Today a fair quantity of LEMIS Baltic's submersible density meters of DM-230 series is used in many countries all over the world.

Table №2.

Technical Specification of submersible instruments DM-230 series

PERFORMANCES	PARAMETERS
Range of: • density, g/cm^3 (kg/m^3) • temperature, °C	 0.6500 - 1.1000 and 1.0500 - 1.5000 650 - 1100 and 1050 - 1500 -30…+50
Accuracy of: • density, g/cm^3 (kg/m^3) • temperature, °C	 ± 0.0005 (± 0.5) ± 0.2
Resolution of: • density, g/cm^3 (kg/m^3) • temperature, °C	 0.0001 (0.1) 0.1

4. Some illustrations of practical tank monitoring using the DM-230 series

The authors of the article has made research work of comparing performances of submersible density/temperature meters DM-230 series of Lemis Baltic and laboratory instruments: DA500 of Kyoto Electronics, glass hydrometer and mercury thermometer. It is necessary to mention, that principles of measurements of LEMIS Baltic and Kyoto instrument are different. Lemis Baltic DM-230 series instruments are based on floating method of measurements, but Kyoto instruments – on resonant (U-tube) method.

Before starting research work, to be sure in operation of all used instruments correctness, authors of the article made verification of all the instruments by the reference (standard) liquids. The admissible divergence in above mentioned readings did not exceed 0.1°C by temperature and 0.5 kg/m³ by density.

The Tables 3, 4 and 5 show the results of parallel density testing in laboratory and "in field".

Table №3.

Density monitoring of the high-octane gasoline and laboratory results for level samples (ASTM), converted to the standard temperature15 °C. Compare of DA500 (Kyoto Electronics, Japan) digital laboratory density meter and DM-230.2 portable/submersible density meter (Lemis Baltic, Latvia)

Sample	DM-230.2, kg/m3	DA500, kg/m3	Δ, kg/m3
ASTM up	756,1	757,8	-1,7
ASTM middle	756,2	757,3	-1,1
ASTM low	756,7	757,5	-0,8
Average	756,5	757,5	-1,0
Mixture of ASTM samples	756,3	758,0	-1,7
Running	756,2	756,8	-0,6

Table 3 results show, that there is a good correlation between the DM-230.2's results for individual level samples and their proportional mixture (composite) - it does not exceed 0.2kg/m3 (756.5 and 756.3 kg/m^3). The same can be said for DA500, whose correlation does not exceed 0.5 kg/m^3, what is good in fact. This case, sampling shows good representation of the average structure of the product in the tank in.

There exists some difference between DM-230.2 and DA500 results (about 0.5 – 1.8 kg/m3), which is natural between two different technologies of density metering. At the same time the difference between these two for reference liquid was not more than 0.3 kg/m3.

Table №4.

Density monitoring of the high-octane gasoline tank density monitoring and laboratory results for level samples (ASTM), converted to the standard temperature 15 °C. Compare of digital laboratory density meter DA500 (Kyoto Electronics, Japan) and DM-230.2 portable/submersible density meter (Lemis Baltic, Latvia).

№	DM-230.2 probe height, m	Density DM-230.2, 15 °C, kg/m3	Height of ASTM sampling, m	Density DA500, 15 °C, kg/m3
1	15.60	766.1	15.92	767.9
2	14.60	766.1	14.24	766.4
3	13.60	765.6		
4	12.60	765.2		
5	11.60	758.6		
6	10.60	757.9	10.39	757.3
7	9.60	757.4		
8	8.60	757.4		
9	7.60	757.6		
10	6.60	757.2	6.54	757.0
11	5.60	756.3	4.86	756.7
	Out of liquid	-	-	-
12	Average	760.5	-	760.4
13	Δ	0.0	-	+ 0.1
14	Average for ASTM samples		-	760.2
15	Δ	0.0	-	+ 0.3

Table 4 results shows two levels with quite different densities in this tank, both laboratory and monitoring shows it clearly. But monitoring can give the height of the two levels more precisely, than sampling. This is a lucky case as the levels are proportional to 1/3 of the total level, so ASTM samples are very representative. In other cases there may be some difference.

Table 4 results show also very good correlation (practically within 0.1- 0.3 kg/m^3) between monitoring and laboratory results. On the other hand it takes about 15 minutes for density/temperature monitoring and more than an hour for sampling and metering.

Table №5.

Temperature monitoring of the high-octane gasoline tank against thermo metering of level samples (ASTM) by mercury thermometer

№	DM-230.2 probe height, m	Monitoring temperature results by DM-230.2, ^{0}C	Height of the sample, m	Temperature of the sample by thermometer, ^{o}C	Δ, ^{o}C
1	15.60	-0.2			
2	14.60	-0.2	14.24	-0.6	0.4
3	13.60	-0.2			
4	12.60	-0.2			
5	11.60	-0.6			
6	10.60	-0.9	10.39	-0.9	0.0
7	9.60	-0.8			
8	8.60	-0.7			
9	7.60	-0.6			
10	6.60	-0.5	6.54	-0.6	0.1
11	5.50	-0.5			
	The surface of the liquid	(-1.5)			
	Average	-0.56		-0.7	0.14

In table 5 it is easy to see two zones with different temperatures and densities in this tank at the same height: 12.60 and 11.60 m. There is a fine match between average results of temperature measurements – 0.14 ^{o}C.

On the other hand there is some difference in the local temperatures in the depth of the tank, which is mainly due to sampling error: the sample goes up through cold layers and its temperature reading becomes lower than in reality. You can see the real problem of weight measuring in tanks with crude oil. This is a typical case, where large gradients of temperature and density exist. The only way - is level-by-level monitoring of the tank.

Table №6.

Crude oil in 1000 m^3 tank monitoring by DM-230.2

№	Level, m	Temperature, ^{o}C	Density at real temperature, kg/m3	Density converted to 20 ^{o}C
1	3.40	8.3	870.4	862.1
2	4.40	8.0	870.9	862.4
3	5.40	7.5	871.2	862.3
4	6.40	6.2	879.8	870.1
5	7.40	5.4	881.2	870.9
6	8.40	4.5	881.5	870.6
7	9.40	4.0	882.1	870.9
8	10.40	3.5	882.1	870.6
9	11.40	3.3	882.9	871.6
10	12.10	3.1	882.1	870.2
11	Average	5.4	878.5 <<	868.2

This tank (pls. see table 6) has a uniform gradient temperature profile: upper level is warm and bottom is cold. But the density profile is not so good. There is a clear border between two different kinds of crude oil in this tank between 5.40 and 6.40 m; the density differs something like 8 kg/m3.

If we compare monitoring and laboratory results we can see a big difference (pls. see Table 7).

Table №7.

Crude oil in 1000 m^3 tank monitoring by DM-230.2 and laboratory results compare

№	Level, m	T, ^oC DM-230.2	T, ^oC Mercury thermometer	Δ, ^oC	Density 20 ^oC, DM-230.2	Density 20 ^oC, hydrometer	Δ, Density 20^oC
1	3.323	8.3	7.6	-0.7	862.1	859.0	-3.1
2	7.923	5.0	4.8	-0.2	870.8	865.0	-5.8
3	12,323	3.1	2.7	-0.4	870.2	864.7	-5.5
4	Average of 1,2,3	5.5	5.0	-0.5	867.7	862.9	-4.8
5	*Average of monitoring*	*5.4*	*5.0*	*-0.4*	*868.2*	*862.9*	*-5.3*

Table 7 shows a big difference can be seen between monitoring and laboratory results, in this case, for both temperature and density. The causes of this difference are question of deep investigation. This is a typical case of the tank with a "difficult" profile where temperature and density monitoring seems to be the shortest way to precise weight measurement.

Being based on the results of the research work, also taking into account positive experience of using portable submersible density meters by many end-users all around the world, can say with certainty, that the use of DM-230 series density/temperature meters is very promising. Mentioned in this article results of the research work and long-term work experience of portable submersible density meters prove, that density/temperature monitoring could decrease risks of errors in weight calculating of the product, save time and money for the user as a result of measuring density and temperature “in the field” directly in the tank without sampling.