DENSITY: A FUNDAMENTAL PARAMETER AT CRITICAL STAGES WITHIN THE PETROLEUM SECTOR

There are many different techniques for measuring the density of liquids and solids, and different places where it can be measured. You can measure directly inline, at the line, or in the lab.

The most reliable and broadly used technique is based on the U-tube principle (see figure 1). This technique centers on an oscillating U-tube where the frequency is measured and density is calculated. For lab instruments, this measuring principle is used with temperature-controlled glass U-tubes. The process density sensors with metal U-tubes work according to the same high-precision oscillating U-tube principle, as per our laboratory density devices. One major difference is that the liquid flows continuously through the U-tubes of the process sensors, which means that temperature changes caused by the ongoing process are measured and the effect on the sensor is automatically compensated.

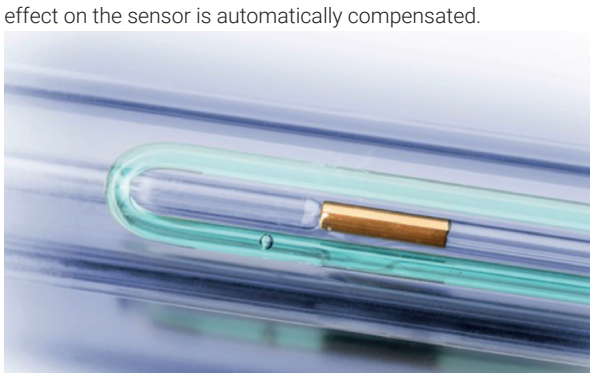

Figure 1: U-tube of benchtop density meter (DMA 4101|4501|5001)

Another technique uses Coriolis mass flow meters. In the context of flow measurement, the Coriolis effect is harnessed to determine the mass flow rate of a substance moving through a vibrating tube. Coriolis flowmeters (see figure 2) consist of a vibrating tube that is initiated to oscillate at its natural frequency. When a fluid (liquid or gas) flows through the vibrating tube, it encounters a Coriolis force due to its motion within the rotating reference frame of the vibrating tube. The resulting twisting motion of the tube is used to determine mass flow rate, whereas the natural frequency is directly proportional to the fluid's density.

Figure 2: L-Cor 8000

One more technique used for semi solids and solids is gas pycnometry. A gas pycnometry measurement consists of placing a sample into the sample chamber and then pressurizing that chamber with gas to a specified value, typically 20 psi above atmosphere. Once the pressure is stabilized, the volume of the chamber is expanded by opening a valve to connect to another chamber, where the volume is known. Comparing the resulting pressure drop to the pressure drop associated with doing the same action when that chamber is empty allows for calculation of the sample volume. The pressure decrease observed when the sample chamber contains a sample will be less than what is observed when the sample chamber is empty.

Table 1: Technologies mentioned in the article

Measuring principle	Anton Paar product
Lab-oscillating U-tube	DMA 35 Ex Petrol, DMA 1001, DMA 4101|4501|5001, DMA 4200 M
Inline-oscillating U-tube	L-Dens 7300, L-Dens 7400
Coriolis mass flow meter	L-Cor 4000, L-Cor 8000
Gas pycnometer	Ultrapyc 3000, Ultrapyc 5000

Advantages of the techniques

The U-tube has various installation options that include a portable hand-held density meter, a benchtop device and an inline. The clear advantage of the intrinsically safe portable hand-held device is that the measurement can be carried out directly on site, e.g. before unloading the tank truck or before loading the tanker in the Ex-zone.

The many advantages of the U-tube technology in laboratory applications include the small sample quantity, the rapid measurement result and the easy cleaning. The measurement results exhibit unparalleled accuracy and repeatability. The devices incorporating this technology stand out for their unique user-friendliness that is further enhanced by the automatic conversion to API or SG, which not only avoids mistakes but also results in significant time savings. A significant benefit of these devices lies in their automation capability, therefore increasing the sample throughput.

The process sensors based on the U-tube measuring principle, which are installed inline, combine the highest accuracy in density measurement with the second-by-second update of measured values. Response times are extremely fast and reliable. The modular design simplifies installation and operation enormously. The measuring principle enables maintenance-free sensors that do not require any consumables. The explosion-proof instruments can be installed in the Ex zone.

Figure 3: L-Dens 7400 Ex installed inline

The Coriolis flow meters combine high levels of density accuracy with very high mass flow rate accuracy. Moreover, their robust performance extends to high temperatures and pressures, reaching up to 350 °C and 400 bar, and accommodating viscosities of up to 10,000 mPas. Additionally, the instrument's explosion-proof design allows for installation in Ex zones.

Gas pycnometry (see figure 4) is very widely used due to its completely inert and non-destructive nature and the speed at which users can obtain results. It proves valuable in evaluating the composition of two-phase solids: It can determine the extent of internal or closed pores within the solid phase itself. In true density measurements, the solid structure of the material is not penetrated and only the pores accessible from the exterior of the material contribute to the results. Because of this, true density measurements are often used to assess the possible presence of closed porosity, by comparing results to a theoretical value of the material, assuming no closed porosity. Weak points in a manufactured part, such as a ceramic mug, can be identified in a matter of minutes with this technique.

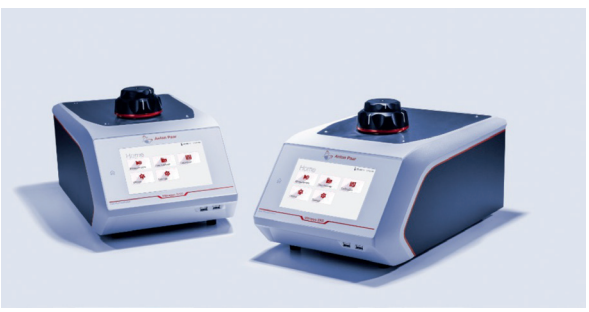

Figure 4: Gas pycnometers: Ultrapyc 3000 and Ultrapyc 5000

The measurement technology used depends on the location of the measurement, the sample, and the desired accuracy. Every application and location have the appropriate measurement technology and a suitable measuring instrument.

Applications:

Upstream

Within the upstream process, there are recognized applications for inline measurement. These encompass the density measurement of drilling fluids, the phase determination between crude oil and saltwater during the desalting process, or the phase detection between water and crude oil in the dewatering process of storage tanks. The ideal instrument for this application is the L-Dens 7300 or L-Cor 8000.

Table 2: Overview of density measuring instruments for portable and laboratory use

	DMA 35 Ex Petrol	DMA 1001	DMA 4101	DMA 4501	DMA 5001	DMA 4200 M	Ultrapyc 3000	Ultrapyc 5000
Accuracy	0.001 g/cm³	0.0001 g/cm³	0.0001 g/cm³	0.00005 g/cm³	0.000005 g/cm³	0.0002 g/cm³	0.02 %	0.02 %
Measuring range temp.	0 °C to 40 °C	15 °C to 60 °C	0 °C to 100 °C			-10 °C to 200 °C	-	15 °C to 50 °C
Standards	ASTM D7777, IP 559	ASTM D4052, D5002, ISO 12185	ASTM D4052, D5002, ISO 12185			ASTM D4052, D5002, D8188	-	-
Applications	Crude oil, fuel, lube	Crude oil, fuel, lube	Crude oil, fuel, lube			Bitumen/ asphalt, crude oil, fuel, lube	Bitumen/ asphalt, lube	Bitumen/ asphalt, lube
Intrinsic safety	ATEX: II 2G Ex ib IIB T4 Gb IECEx: Ex ib IIB T4 Gb							

Table 3: Overview of Process measuring instruments

	L-Dens 7300 SST Ex d	L-Dens 7400 SST Ex d	L-Dens 7400 HAS HP Ex d	L-Cor 8000	L-Cor 4000
Accuracy	0.5 kg/m³	0.1 kg/m³	0.1 kg/m³	Mass flow: 0.1 % Density: 0.5 kg/m³	Mass flow: 0.2 % Density: 3 kg/m³
Measuring range	max. 1,500 kg/m³	max. 3,000 kg/m³	max. 3,000 kg/m³	max. 2,000 kg/m³	max. 2,000 kg/m³
Temperature range	-40 °C to 125 °C			-200 °C to 200 °C	-40 °C to 130 °C
Max. pressure	50 bar	50 bar	180 bar	Acc. flange pressure rating	Acc. flange pressure rating
Wetted parts	1.4404 (316L)	1.4404 (316L)	alloy C-276	1.4404 (316 L), alloy C-22	1.4404 (316L)
Applications	Drilling fluids, crude oil, intermediate & final products of refineries, biofuels, ethanol and liquefied gases			Mass flow measurement in each production step, density control, custody transfer	Mass flow measurement in each production and density control step
Ex certification	ATEX, IECEx, cQPSus, INMETRO, Peso, GB certified			ATEX, IECEx, CSA, NEPSI	

Midstream

Ensuring the accurate quantity of crude oil is crucial when it comes to trading. DMA benchtop density meters, such as the DMA 4501 and DMA 5001, provide reliable density measurements for calculating weight from known volumes. Operating at a suitable temperature, these devices offer quick and precise results, with the DMA 5001 providing enhanced accuracy through 6-digit results. Dual control features, including real-time camera monitoring (U-View ™) and automatic filling error detection (FillingCheck ™), ensure measurement reliability. As well as volume to mass conversion, L-Cor 8000 Coriolis mass flow meters are used for custody-transfer compliant total mass measurements.

Downstream

Density measurement becomes imperative once again as distillated products undergo treatment, blending, storage, and are prepared for transportation and trading to other companies for further processing and sale. Ensuring that the refined product aligns with all specification requirements is paramount. The accurate classification, determined through API gravity measurement, serves as the foundation for converting volume to mass, and vice versa, for sales transactions. Utilizing advanced density meters like the DMA 4501 or the DMA 5001 with 5-digit and 6-digit precision, respectively, ensures accurate mass-per-barrel calculations, providing a solid basis for successful deals.

For on-the-spot density checks at terminals, the DMA 35 Ex Petrol (see Figure 5) handheld density meter is intrinsically safe and is invaluable in such situations. This device stores relevant unit conversions and records results, which can be conveniently transferred to a PC or printer later.

Figure 5: Intrinsically safe DMA 35 Ex Petrol in use in hazardous area

An alternative approach is to integrate a process density sensor directly into the loading and unloading line, making the L-Dens 7400 the appropriate instrument for this purpose. In this configuration, the inline density sensor plays a key role in product identification, volume to mass conversion and quality control, while the Coriolis flow meter accurately measures the pumped quantity and quality, enabling the custody transfer compliant direct measurement of total mass.

Additionally, L-Dens 7400 is used for custody transfer and fiscal measurement, especially when highest density accuracy is required. When refueling aircraft, the exact density measurement of the jet fuel with L-Dens 7400 for the conversion of volume to mass is of the utmost importance for safe flights and the economic efficiency of the airline.

Official product certification requires the use of a benchtop density meter in the controlled environmental conditions of a laboratory to achieve utmost accuracy. Automating a digital density meter with a sample changer, such as the Xsample 630 compatible with DMA 4101/4501/5001 density meters (see figure 6), facilitates measurements even during non-working hours, covering a broad temperature range and accommodating various products, including lubricants and waxes.

Figure 6: DMA 4501 plus Xsample 630

In the trade of bitumen/asphalt and other heavy petroleum products, digital density measurement emerges as a swift and precise alternative to traditional methods like hydrometers and pycnometers. The DMA 4200 M density meter stands out as a reliable tool for density measurement under elevated temperatures and pressures, adhering to ASTM standards including D4052, D5002 and ASTM D8188. The ASTM D8188 method in particular provides a faster and more accurate alternative to ASTM D70, making density checks on asphalt, asphalt binder, and bitumen 10x faster. The DMA 4200 M ensures constant temperature control throughout the process, from syringe to inlet and outlet, facilitating the filling of fluid bitumen/asphalt or residual fuel oil.

Measuring the density of asphalt, lubes and greases is a tedious process when using a glass pycnometer. Weighing and cleaning a manual glass pycnometer is time-consuming and doesn't guarantee accurate results.

Ultrapyc 5000 is a temperature-controlled gas pycnometer, offering a quick and accurate way to get density results in minutes. Ultrapyc also comes with disposable cups which makes the sample weighing and cleaning process seamless for bitumen samples.

Portfolio and compliance

The assessment of density and related parameters, such as API gravity, constitutes a daily task for tens of thousands of individuals in the crude oil and petroleum industry. Density measurement at-line, inline or in the lab ensures streamlined measuring routines and delivers precise, reliable results efficiently.

Conclusion

Discover our extensive range of handheld density meters, benchtop density meters, gas pycnometers, inline density (see Figure 7) and mass flow meters that are tailored for a wide variety of applications in the petroleum industry. Even under the most challenging conditions, our instruments and sensors offer unparalleled measurement accuracy, ensuring optimal monitoring and product quality. Avoid unnecessary expenses - trust Anton Paar, your reliable partner in accurate density measurement in the lab and in the process.

Figure 7: Overview of density portfolio for petroleum industry

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