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## Metering & Measurement

**Coriolis**

**Differential Pressure**

**Uncertainties**

**SwRI Model**

**Liquids**

**GIS**

**LNG Simulation**



# Measuring Flow Of High-Viscosity Liquids

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**M**easuring custody transfer of high-viscosity fluids has always presented challenges, and as the world relies increasingly on heavy crudes with various amounts of wax, bitumen and sand, the challenge increases. Crude oils typically flow at rates up to 50,000 barrels per hour (BPH) at export terminals, up to 1,500 BPH at ship- and truck-loading facilities and to 7,000 BPH in pipelines.

In addition to heavy crude, other challenging high-viscosity products include heavy fuel oils, bunker fuels, lubricating oils, grease components, and asphalts. In most cases, flow requires elevated temperatures – up to 400 °F (205°C) – and flowmeters must be reliable in this environment.

This article will recap measurement problems related to viscosity and flow and discuss the choice of equipment available to meet the challenges, plus special design, operational and maintenance requirements.

## Viscosity, Specific Gravity And Temperature

We consider a viscous hydrocarbon to be any liquid hydrocarbon that requires special treatment or equipment in order to be handled or stored.

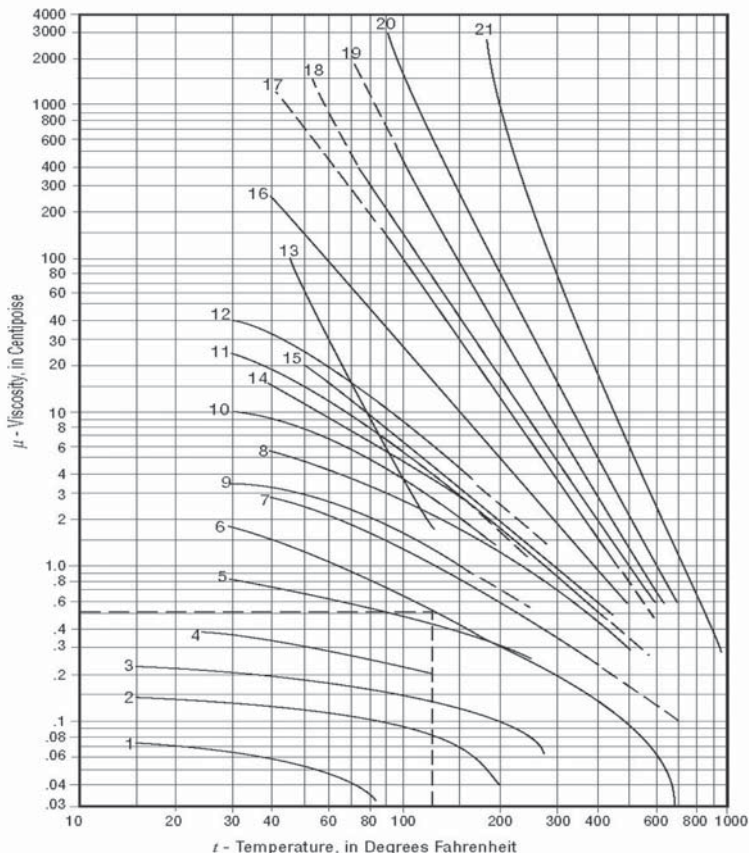
Viscosity (resistance to flow) is related to specific gravity (density), although the relationship between the two is not direct, as the table below shows.

In addition, each hydrocarbon has a characteristic viscosity vs. temperature curve, making it possible to infer viscosity for known stable hydrocarbon mixtures using a curve developed in the laboratory. In cases where mixtures of hydrocarbons vary over time, viscosity can be measured using one of the many on-line viscometers available.

The figure in this article shows viscosity-

temperature curves for the same fluids. In all cases, viscosity decreases with increasing temperatures, but the decline may be more or less dramatic.

**Viscosity of Water and Liquid Petroleum Products**



**Example:** The viscosity of water at 125°F is 0.52 centipoise (Curve No. 6)

**Typical Viscosity and Specific Gravity of Petroleum Products\***

Product	Typical Viscosity in cP** @ Degrees F (Degrees C)						S.G. @ Degrees F (Degrees C)		
	30 (-1)	60 (15)	100 (38)	150 (66)	300 (150)	400 (205)	60 (15)	150 (66)	
Ethane -LPG	0.07	0.05	0.03				0.38	0	
Propane -LPG	0.14	0.12	0.09	0.07			0.51	0.41	
Butane - LPG	0.20	0.18	0.15	0.13			0.56	0.49	
Gasoline	0.83	0.63	0.49	0.38			0.75	0.70	
Water	1.8	1.2	0.7	0.4	0.2	0.1	1.00	0.95	
Kerosene	3.5	2.2	1.7	0.9	0.4	0.2	0.82	0.77	
Jet Fuel	3.5	2.2	1.7	0.9	0.4	0.2	0.82	0.77	
48 API Crude	3.5	2.7	1.7	1.1			0.79	0.74	
40 API Crude	10	7	4	2			0.82	0.77	
35.6 API Crude	25	16	6	3			0.85	0.80	
32.6 API Crude	42	21	9	5			0.86	0.81	
Fuel 3 (Max.)		10	5	3	1	0.5	0.90	0.85	
Fuel 5 (Min.)		16	7	4	1	0.6	0.97	0.92	
Fuel 6 (Min.)			820	150	43	5	2	0.99	0.94
SAE 10 Lub			68	29	11	2	1	0.88	0.83
SAE 30 Lub			450	105	31	4	2	0.90	0.85
SAE 70 Lub				460	95	8	3	0.92	0.87
Bunker C				1500	290	16	5	1.01	0.96
Asphalt					>3000	80	19	0	0

\*Data made available from the Crane Co.  
\*\*Centipoise (cP) = Specific Gravity (S.G.) x Centistokes (cSt).

1. Ethane (C2H6)
2. Propane (C3H8)
3. Butane (C4H10)
4. Natural Gasoline
5. Gasoline
6. Water
7. Kerosene
8. Distillate
9. 48 Deg. API Crude
10. 40 Deg. API Crude
11. 35.6 Deg. API Crude
12. 32.6 Deg. API Crude
13. Salt Creek Crude
14. Fuel 3 (Max.)
15. Fuel 5 (Min.)
16. SAE 10 Lube (100 V.I.)
17. SAE 30 Lube (100 V.I.)
18. Fuel 5 (Max.) or Fuel 6 (Min.)
19. SAE 70 Lube (100 V.I.)
20. Bunker C Fuel (Max.) and M.C. Residuum
21. Asphalt

## Measurement Alternatives

Measuring flow in fluids with viscosities above 100 cp requires special consideration by those charged with designing, operating and maintaining the equipment. The sliding vane positive displacement meter has been the first choice for measurement since the 1930s; however, in the last 10-15 years other technologies have emerged that can offer improved cost/benefit ratios, depending on the viscosity and temperature of the fluid and the required accuracy of the meter. Most custody transfer flowmeters fall into one of four categories:

- Positive displacement (PD) meters
  - Helical turbine meters
  - Coriolis meters
  - Liquid ultrasonic meters

The positive displacement meter is the only direct measuring alternative, in that every molecule of fluid passes through the meter. The other technologies infer total flow by measuring velocity within a separate flow conduit, where changes in the physical properties of the fluid or of the conduit itself increase the uncertainty of the measurement.

This disadvantage can be overcome by proving the meters on a regular basis and monitoring fluid characteristics to be sure the meter read-out has not gone beyond acceptable tolerances. Inferential meters can also be influenced by upstream (and to a lesser extent downstream) flow conditions, such as elbows, strainer debris or partially open valves.

In defining appropriate flowmeters for given conditions, the total turndown range is key. In general, turndown range is the range of flow rates over which a meter will perform within a specified linearity, usually +/- 0.15%.

There are two components of the total turndown range: the viscosity turndown range (which depends on the viscosity/flow relationship), and the meter turndown range (which depends largely on the type of meter). Each of the four technologies noted above has a characteristic turndown range, defined as the ratio of the maximum flow rate divided by the minimum flow rate. The higher the turndown range, the greater the range of flow rates over which the meter will be linear.

The total turndown range is equal to the flow turndown range multiplied by the viscosity turndown range. If meters are operated within a narrow band of flow rate and viscosity and proved at flow rates and viscosities close to these, linearity becomes less of a factor, and meter performance becomes more repeatable. Meter linearity is less of an issue with large parcels such as pipeline and ship loading/unloading applications but becomes more important in truck loading, rail-car loading, bunkering, and other small-parcel applications.

Most of the very high-viscosity refined products are handled at temperatures above ambient to facilitate pumping, transportation and metering, so it is important to specify measuring component materials that can withstand the elevated temperatures provided by steam, hot oil, or electric heat-traced and recirculation lines. In cases where it is uneconomical to heat large quantities of high-viscosity crudes, they are treated with diluents to enable transportation and metering at near-ambient temperatures.

## Meter Selection And Sizing

This section lists the advantages and disadvantages of the four meter types used for high-viscosity fluids and shows graphs of suitability depending on viscosity and flow rate.

### Positive Displacement Meters

#### ▲ Advantages

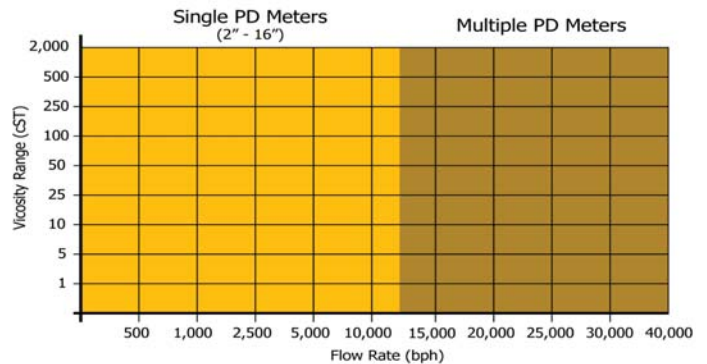
- High accuracy over a wide range of viscosities and flow rates up to 2,000 cST with proper clearances
- Extremely good repeatability on high-viscosity fluids, very low slippage, long life if there is little or no abrasive material in the fluid
- Low pressure drop
- Functions without external power
- Special construction available for high viscosities and temperatures
- Can register near zero flow rate
- Flow conditioning not required
- Measures directly, not an inferential device, for more consistent results

#### ▼ Disadvantages

- More moving parts leads to increased maintenance compared to other meters

- May become damaged by flow surges and gas slugs
- Chance of corrosion and erosion from chemicals and abrasive materials
- Derated flow rate capacity for high viscosities and temperatures
- Relatively high cost for large meter sizes, since all fluid must pass through the meter

### PD Meter Measurement Range



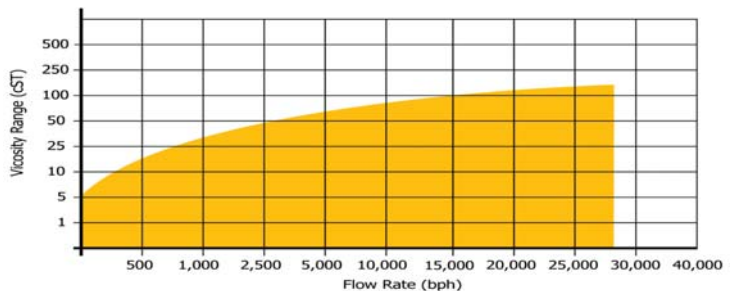
### Helical Turbine Meters

#### ▲ Advantages

- Higher turndown range on high-viscosity crudes than conventional turbine meters
- Very good repeatability
- Reduced susceptibility to fouling, abrasives and deposits
- Less sensitive to viscosity changes
- Lower pressure drop than conventional turbine meters
- Available in large sizes, providing good value for high flow rates

#### ▼ Disadvantages

- Requires flow conditioning
- Back pressure required
- Requires pulse interpolation due to low-resolution pulses
- An inferential device



### Coriolis Meters

#### ▲ Advantages

- Low maintenance, minimally affected by abrasives and corrosives
- Not susceptible to damage by gas slugging
- Registers near zero flow rate
- Minimally affected by viscosity changes
- Direct mass and density measurements
- Flow conditioning not normally required

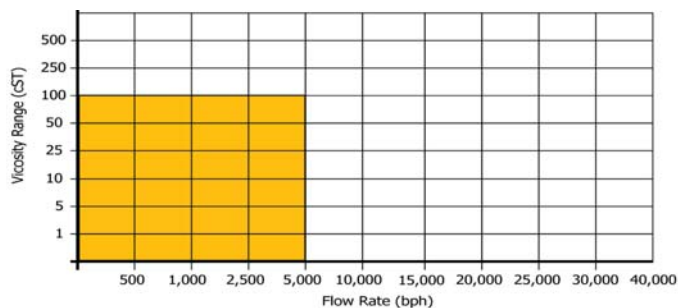
#### ▼ Disadvantages

- Sensitivity to installation conditions, including shock, vibration, pulsations and effects of adjacent parallel runs
- Deposits can affect accuracy
- Difficult to prove due to time lag of the pulse output
- Requires periodic re-zeroing
- Needs back-pressure control
- High pressure drop that increases drastically with viscosity
- An inferential device

### Liquid Ultrasonic Meters

#### ▲ Advantages

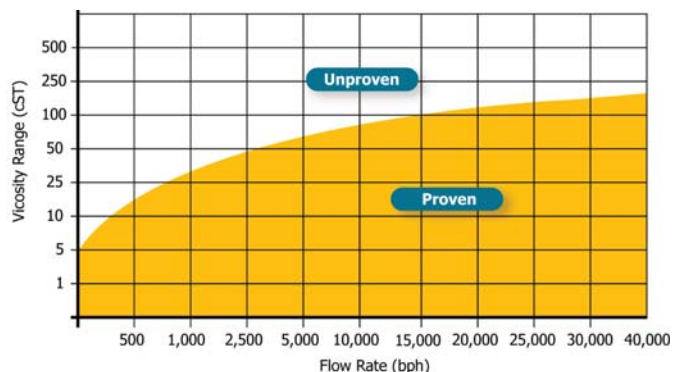
- High accuracy
- Wide dynamic flow range
- Negligible pressure drop



- Non intrusive and no moving parts, making this the least influenced by abrasive materials
- Diagnostic capabilities
- No need for upstream strainer
- Self diagnostic capabilities

#### ▼ Disadvantages

- Flow conditioning recommended
- Susceptible to fouling or deposits
- Sensitive to installed conditions
- Sampling and microprocessor-based output contributes to difficulty in proving
- High cost for small sizes
- Maximum size limited by proving capability
- Back pressure required
- An inferential device



## Operational Issues

### Air Removal

All of the meter types discussed require the removal of entrained air and/or vapor which may be difficult with most viscous liquids. As viscosity increases, so does the time required to separate fine bubbles of air or vapor from the liquid. A vapor removal system may be required and a number of such systems are available.

### Proving The Meters

For custody transfer applications, all of the inferential meter types described above must be periodically proved at conditions close to operating temperature, viscosity, gravity, flow rate and pressure. For high flow rates, in-situ pipe provers are recommended. For lower flow rates, portable proving equipment or master meters may be used.

Although all proving methods may be used with high-viscosity fluids, pipe provers have an inherent advantage over tank provers because the displacer seal against the pipe wall ensures that all fluid is measured. When a tank prover is used, the operator should be alert to high-viscosity fluid clinging to the tank wall because this will affect the measurement. The amount of clingage will vary with the temperature and it is difficult to control temperature within a tank.

Pipe provers used in above-ambient temperatures should be insulated and possibly even steam- or electrically heat traced. Make sure that the maximum operating temperatures of the elastomer prover displacer sphere and the internal prover coatings are sufficient to handle fluid temperatures.

### Readout And Control Equipment

Since most high-viscosity liquids are handled at line temperatures far above the 60°F reference temperature, accurate electronic temperature compensation of integrated volumes is essential, and we recommend electronic flow computers. For large systems where several meters operate in parallel, we recommend supervisory computers capable of

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automatic proving plus temperature monitoring and control.

For small stand-alone PD meters deployed where no power is available, mechanical wheel and disk temperature and gravity compensators (ATG and ATC) are still available, although they are not as accurate as electronic compensators.

### Special Operational And Maintenance Considerations

For viscous hydrocarbons heated above ambient, it is essential to monitor and control temperature carefully, because viscosity increases so drastically with a drop in temperature. If the temperature of the system decreases enough that the pumps cannot sustain flow, pump damage can result. Removing solidified product from the pipelines and metering equipment can be very difficult and expensive.

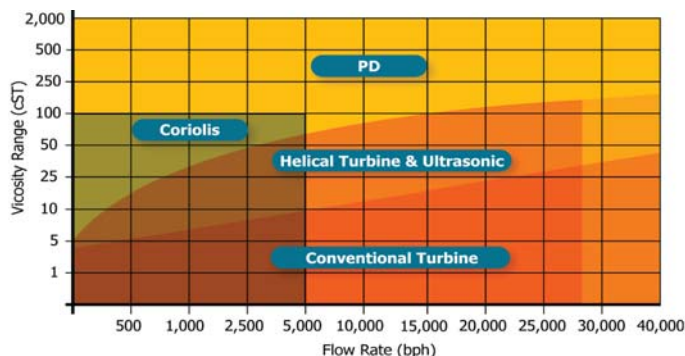
If systems are used intermittently, it may be more practical to evacuate or flush them with a low-viscosity solvent between uses. Upon restarting, fill the system slowly and evacuate air or vapor completely before resuming flow, since the meters and other components can be damaged by gaseous slugs.

If the temperature control system fails and temperatures rise too high, serious damage to valves, meters, and provers can occur. In addition, overheating the fluid can cause coking or chemical changes – and some overheated petroleum liquids may ignite on exposure to air.

Hydraulic considerations are also important since the pressure drop in the measuring system will increase dramatically with an increase in fluid viscosity. Pump sizing assumptions become very important. For example, consider a crude oil with 12 API Gravity and viscosity of 300 cP @180°F and 6,500 cP @ 60°F. The maximum flow rate desired is 6,000 BPH – but will this really be achieved when the product is heated? This needs to be confirmed. If this flow rate can be achieved, what is the maximum flow rate that is hydraulically possible when the viscosity falls to 6,500 cP?

## Conclusions

The figure below shows a composite of the four technologies. While there are many choices of flowmeters for high-viscosity liquids, no single metering technology is best for all applications.



For abrasive-free liquids, positive displacement meters can handle the widest range of flow rates and viscosities and will have a very long life. They have a track record of in-field service of over 70 years, and some meters are still in operation after 30 years on heavy, waxy crudes. For applications where future liquid viscosities and flow rates are uncertain, positive displacement meters are the most flexible.

Helical turbine meters offer the lowest cost alternative for high flow rates on high-viscosity, abrasive-free fluids.

Coriolis meters perform well within their limited flow and viscosity range although they have high pressure drops.

Ultrasonic meters only become economically attractive for very high flow rates and are the best at accommodating abrasive fluids.

Selecting the proper ancillary equipment is essential to meter performance and equipment operation and maintenance of high-viscosity flowmeters may require special techniques unique to each application. **P&GJ**

#### ACKNOWLEDGEMENTS

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#### REFERENCES

1. API Manual of Petroleum Measurement Standards Chapter 1 "Vocabulary" provides a comprehensive list of definitions for many of the terms used in this paper.
2. API Manual of Petroleum Measurement Standards Chapter 6. "Metering Viscous Hydrocarbons" provides a comprehensive guide for the design, installation operation and proving of meters and their auxiliary equipment used in metering viscous hydrocarbons.