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7. Abstract

This report documents the search results in identifying manufacturers who can develop viscosity sensors for in situ to waste characterization. Six companies were found that have in-process viscometers.

10.

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MASTER

VENDORS SEARCH
FOR
VISCOSITY SENSORS FOR IN SITU TANK WASTE CHARACTERIZATION

July 27, 1994

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P.O. Box 1970
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VENDORS SEARCH FOR VISCOSITY SENSORS FOR IN SITU TANK WASTE CHARACTERIZATION

1.0 OBJECTIVE

The objective of this study is to identify current technologies and manufacturers who can develop viscosity sensors for in situ tank waste characterization.

1.1 BACKGROUND AND SCOPE

Tank waste characterization is essential in the development of design criteria for choosing retrieval equipment and developing tank waste simulant. One important physical property of tank waste is the viscosity of the sludge. Viscosity is a measure of the deformation and the flow of matter. In general, the term viscosity is used in relating to fluids and semi-solids such as plastics, rubber, soil, drilling muds, cement, paints, slurries, or food products. The fact that tank waste slurries do not behave in a classical or "Newtonian" (Azbel et al. 1983, Hansen 1967) manner leads to the need for in-tank characterization. The viscosity is defined as the ratio of the shear stress over the corresponding shear rate at a specified temperature and pressure. The viscosity sensor can also be referred to as viscometer.

A vendor list and their catalogs will be compiled based on a product search using the keyword "viscometer" on the Vendor Master Directory on CD-ROM¹ (IHS 1994). The conclusions from this report are based on the review of these catalog pages.

1.2 PURPOSE AND NEED

The purpose of this study is to survey current market and identify well-defined methods or technologies and/or manufacturers to develop viscosity sensors meeting the criteria in Section 5.1.

2.0 SUMMARY

This study evaluates existing viscosity sensors from various vendors in search of a measurement device for in-tank measurement of tank waste viscosity.

¹ The Vendor Master Directory is a catalog database on CD-ROM that has approximately 25,000 vendors. The catalog contains vendors addresses, sales office and distributors, and a description of products plus full hard copy of catalog pages.

The impacts of not performing this study are as follows:

1. A better viscosity sensor might not be used.
2. Additional expenses and times are needed to develop a new viscosity sensor.

3.0 RECOMMENDATIONS AND CONCLUSIONS

The recommended viscometers for use in tank waste characterization are those from Brookfield Engineering Laboratories, Inc., Cole-Parmer Instrument Co., Conameter Corp., Fisons Instruments, Mettler-Toledo, Inc., and Nametre Co. These companies are not listed in any particular order. Further contact with these vendors is necessary to decide the readiness of their sensors for in-tank deployment. Table 3.1 shows the summary of all viscosity sensor developers found in this search.

Table 3.1. List of Viscometer Vendors.

Manufacture	Method	Laboratory	In-Process
B Y K-Gardner, Inc.	Bubble Viscometer	Y	
	Viscosity Cups	Y	
Barnant Co.	Falling Ball	Y	
Baroid Drilling Fluids, Inc.	Viscosity Cups	Y	
	Rotating Cylinder	Y	
Brabender Instruments, Inc.	Modified rotational cylinder	Y	
	Oscillating Shear-Disc	Y	
Brookfield Engineering Laboratories, Inc.	Rotating Spindle	Y	Y
Cannon Instrument Co.	Rotating Spindle	Y	
Cole-Parmer Instrument Co.	Piston		Y
	Rotating Spindle	Y	
	Falling Ball	Y	
Conameter Corp.	Balance Capillary		Y
Cookson America, Inc.	Spiral Screw	Y	
Tekmar Co.	Rotating Spindle	Y	

Falex Corp.	Rotating Spindle	Y	
Fisons Instruments	Vibrating Cylindrical Rod		Y
	Rotating Cylinder	Y	
Kaltec Scientific, Inc.	Rotating Cylinder	Y	
Mettler-Toledo, Inc.	Rotating Cylinder		Y
Nametre Co.	Rotating Spindle	Y	Y
	Vibrating Sphere	Y	Y
Ruska Instrument Corp.	Falling Ball	Y	
Core Laboratories Instruments	Falling Ball	Y	

4.0 UNCERTAINTIES

The uncertainty in this study is the information claimed by manufacturers in their catalogs. The information can be either viscosity range, shear rate range, shear stress range, accuracy, or repeatability. It is trusted that their statements are accurate and reliable.

5.0 DESCRIPTION OF ALTERNATIVES AND SOLUTIONS

5.1 CRITERIA

All viscometers selected in this report must meet the following criteria:

1. Technologies must exist and have been used successfully in the industries.
2. Use of the sensor in waste tank characterization shall not require development (it can have minor mechanical modification).

5.2 ASSUMPTIONS

The assumptions in this study are as follows:

1. This study assumes that radiation-hardened materials and equipment can be used to develop the sensor for in-tank operation.

2. The accuracy of the viscosity value measured may depend on material temperature, pressure, and density. This study assumes that these quantities can be measured and the results are accurate and ready to use.
3. The size and shape of the viscometer may be scaled to meet the requirements imposed by the Light Duty Utility Arm (LDUA) deployment system and tank environment.
4. This study assumes that the desired viscosity ranges can be met by the manufacturers.

5.3 ALTERNATIVES

The alternative viscosity measurement methods that will be evaluated are balance capillary, Brabender viscometer, bubble viscometer, falling ball, oscillating shear-disc, rotating spindle, rotating coaxial cylinder, spiral screw, viscosity cups, vibrating cylindrical rod, and vibrating sphere. (See Appendix A of this document)

5.3.1 Balance Capillary Viscometer

An electric motor-driven gear pump in the balance capillary viscometer continuously pulls a small amount of fluid, flowing in the housing, through an inlet capillary tube at a constant flow rate. This flow is then forced through an identical outlet capillary tube. The flow characteristics of fluid are such that the resistance to flow (differential pressure) through a capillary is directly proportional to viscosity. Since both capillary tubes are identical, the differential pressure measurement is twice the differential across each capillary tube. This unique Balanced Dual Capillary principle assures that rapid changes in line pressures, such as encountered in diesel engines, does not affect the viscosity measurement. A manufacture for this type of viscometer is Conameter Corporation.

This instrument was designed for in-process measurement.

5.3.2 Brabender Viscometer

In the Brabender viscometer, the fluid is placed into a cylindrical stainless steel bowl with eight fixed vertical pins. The bowl is rotated at a constant speed of 75 rpm to provide a fixed shear rate to the fluid. The shear rate can be changed by using a variable speed motor. The fluid is maintained at a constant temperature by an immersed thermometer which regulates an electrical heater in a heating jacket surrounding the bowl. The sensing element consists of a plate with seven pins extending into the test fluid. This sensing element also acts as a stirrer. The deflection of the stirrer depends upon the viscosity of the test fluid. The resistance encountered is transmitted to the spring system and continuously recorded by a recording mechanism. The sole manufacturer for this viscometer is Brabender Instrument, Inc.

The available instrument was designed for laboratory uses. However, the method may still be applicable for in situ measurement. Such modification can be done by immersing and rotating the stirrer while measuring the deflection instead of rotating the bowl container.

5.3.3 Bubble Viscometer

In a bubble viscometer, the test fluid is trapped inside a tube with an air space on top. The tube is then inverted to allow the air bubble to rise. The time it takes for the bubble to reach the top is a direct measurement of the kinematic viscosity. The tube length, size, temperature, amount of test fluid, and air bubble must be precisely controlled. A manufacture for this type of viscometer is B Y K-Gardner, Inc.

This method is not applicable for in-tank measurement, because tank waste uniformity and temperature are unknown and uncontrollable. The bubble viscometer will not be considered any further.

5.3.4 Falling Ball Viscometer

A falling ball viscometer consists of a glass tubing with a flat base and a ball. The tube, with the ball at the bottom, is inverted to allow the ball to descend. The rate at which the ball falls through the fluid can be used to calculate the viscosity of the test fluid. Manufacturers using this method are Barnant Co., Cole-Parmer Instruments, Inc., Ruska Instrument Corporation, and Core Laboratories Instruments.

A modified version of this method is the falling ball with an attached string. The tension of the string is monitored as the ball falls at a constant and controlled rate. The tension information is then converted to the viscosity value.

5.3.5 Oscillating Shear-Disc Viscometer

The oscillating shear-disc viscometer consists of two discs which are horizontally installed and face each other in parallel. The shear-disc is maintained above the sample-disc with an adjustable gap. The test fluid will fill the gap between the two discs. In operation, the sample-disc oscillates at an adjustable frequency and with a constant oscillating angle to give a shear moment at the shear-disc. The shear moment is measured by a torque measuring device connected to the shear-disc. The maximum shear depends on the viscosity of the sample fluid. The temperature for each disc is kept at a constant value by means of an electronic regulator. The sole manufacturer for this viscometer is Brabender Instruments, Inc.

This instrument was designed for laboratory uses and therefore cannot be used for in situ measurement without further modification. This method will not be considered any further.

5.3.6 Piston Viscometer

The viscosity value for this system is determined by applying an electromagnetic force to the sensor's piston. The piston's motion is impaired by the viscosity of the liquid. The electronic monitor then converts the movement into an accurate viscosity measurement. The piston is the only moving part; therefore, there will be no damage from possible fluid leakage. A distributor for this device is Cole-Parmer.

This instrument was designed for in-process measurement.

5.3.7 Rotating Spindle Viscometer

In the rotating spindle viscometer, the viscosity is measured by sensing the torque required to rotate a spindle at a constant speed while immersed in the sample fluid. The torque is proportional to the viscous drag on the immersed spindle, and thus to the viscosity of the fluid. There are several advantages to the rotational viscometer: the continuous rotation of the spindle allows uninterrupted measurements; the rate of shear the sample fluid is subjected to is constant, so the instrument is suitable for measuring Newtonian and non-Newtonian fluids; and the shear rate can be changed by varying the rotating speed of the spindle. This product can be found through Brookfield Engineering Laboratories, Inc., Cannon Instrument Company, Cole-Parmer Instrument Company, Teckmar Company, Falex Corporation and Nametre Company.

The in-process rotating spindle viscometer is currently available. Accuracy is unaffected by changes in temperature, pressure, or flow. Some models were built using pneumatic operation which makes it safe for hazardous areas. For instance, the Brookfield TT200 Process Viscometer can be built with explosion proof construction, Class 1, Division 1 & 2, Groups C & D or NEMA 4 Construction.

5.3.8 Rotating Cylinder Viscometer

Rotational viscometers usually consist of a cylinder rotating in a static measuring cup filled with the sample. The rotor is driven at fixed or programmable speeds. The resistance of the sample to flow causes a very small movement in a torsion bar, mounted between the motor and the drive shaft. This movement or deflection is detected by an electronic transducer. Signals proportional to the speed and torque are transmitted to the control unit for processing and display. This rheogram of speed vs. torque is converted into shear rate vs. shear stress or shear rate vs. viscosity. This method can be used for both Newtonian and non-Newtonian fluids. Another version of this method is to rotate the outer cylinder or cup at a known speed while monitoring the viscous drag on the inner cylinder. The advantage of both methods is that this method permits the true simulation of the flow process conditions. Some manufacturers for this type of viscometer are Baroid Drilling Fluids, Fisons Instruments, Kaltec Scientific, Inc., and Mettler-Toledo, Inc.

From the cited vendors, only Mettler-Toledo, Inc. uses this method for in-process measurement.

5.3.9 Spiral Screw Viscometer

The spiral screw viscometer consists of a stationary threaded cylinder surrounded by an outer rotating cylinder. This set-up is similar to the spiral pump design. The combination of thread and outer rotating cylinder causes the test fluid to be continually pumped up through the spiral mechanism. The fluid which is being pumped through the spiral/cylinder arrangement reaches a steady state of flow. It is under this steady state condition that viscosity is measured. Various rotational speeds (shear rates) can be selected, thus providing viscosity data at these shear rates. The manufacturer for this product is Cookson America, Inc.

This instrument was design for laboratory uses but the method is adaptable for in situ measurement.

5.3.10 Viscosity Cups

The viscosity cup is a simple device that permits the timed flow of a known volume of test fluid passing through an orifice. At least 50 types of flow cups have been developed and used over the years, mainly for in-plant production control and field inspection purposes. Most of these cups are of two main types: mounted on a stand for filling and draining or dipped directly into the fluid before draining back into the same container. In this test, simply fill the cup with the test fluid and measure the time it takes until the steady stream coming out of the cup first begins to drip. Manufacturers for this type of viscometer are B Y K-Gardner, Inc. and Baroid Drilling Fluids, Inc.

Although this method can be done for in-tank tests, the results are not very accurate.

5.3.11 Vibrating Cylindrical Rod Viscometer

The operating principle is based on a patented vibrating cylindrical rod system. The rod is held in oscillation by an electronic positive feedback circuit and magnet coil device. This circuit generates a vibration of the sensor rod at its resonance frequency. Changes in substance viscosity are measured according to the amplitude damping of the rod. The higher the viscosity, the more the amplitude is damped. These damping signals are processed electronically and transformed into DC voltage and standard current outputs. These control signals allow the viscometers to be inserted into any regulation loop to maintain acceptable process conditions. Manufacturer for this product is Fisons Instruments.

This instrument is designed for in-process monitoring. Products are available to use in an intrinsic safety requirement.

5.3.12 Vibrating Sphere Viscometer

The standard sensor probe has a stainless steel tube which houses a drive shaft for a ball connected at the end of the tube. During operation, the drive shaft delivers a torsional oscillation amplitude of 1 micron to the ball. When viscosity changes, the viscometer varies the power input to maintain a constant oscillation amplitude. The power requirement indicates

viscosity. Either a cylinder or a rod can be used in place of the sphere depending on the measurement range. This method can measure both Newtonian and non-Newtonian materials. Manufacturer for this product is Nametre Co.

This instrument is designed for both in laboratory and in-process monitoring.

6.0 DISCUSSION OF PREFERRED ALTERNATIVE/SOLUTION

Based on the availability of current in-process (or in situ) sensors, Table 3.1 lists the companies that can develop viscosity sensor(s). Note that some methods for laboratories use can be modified for in-process monitoring. One example is the falling ball method with a string attached which is under development by WHC jointly with the Battelle Pacific Northwest Laboratory.

From Table 3.1, six of the companies currently have viscometers for in-process or in situ measurement. They are Brookfield Engineering Laboratories, Inc., Cole-Parmer Instrument Co., Conameter Corp., Fisons Instruments, Mettler-Toledo, Inc., and Nametre Co.

The factors not discussed in this search are cost, viscosity ranges (manufacturers usually can modify their products to fit a particular project), and the response times. Further communication with vendors is necessary to address these specific areas.

7.0 REFERENCES

- Azbel, D. S., and Cheremisinoff, N. P., 1983, *Fluid Mechanics and Unit Operations*, Ann Arbor Science, Ann Arbor, Michigan.
- Hansen, A. G., 1967, *Fluid Mechanics*, John Wiley and Sons, Inc., New York.
- Information Handling Services® (IHS), 1994, *Vendor Master Directory on CD-ROM*, Englewood, Colorado.

APPENDIX A - LIST OF COMMERCIAL VISCOMETER DEVELOPERS AND DISTRIBUTORS

1. Vendor Name: B/R INSTRUMENT CORP
Address: 9119 CENTERVILLE RD
EASTON, MD 21601 USA
Phone: 410/820-8800
Fax: 301/820-8141
2. Vendor Name: B Y K-GARDNER INC
Address: 2435 LINDEN LN
SILVER SPRING, MD 20910 USA
Phone: 301/585-7150, 800/343-7721
Fax: 301/585-4067
3. Vendor Name: BARNANT CO
Address: 28W092 COMMERCIAL AVE
BARRINGTON, IL 60010 USA
Phone: 708/381-7050, 800/637-3739
Fax: 708/381-7053
4. Vendor Name: BAROID CORP/BAROID DRILLING FLUIDS INC
Address: 3000 N SAM HOUSTON PKY E PO BOX 1675
HOUSTON, TX 77251 USA
Phone: 713/987-6040
Fax: 713/987-6070
5. Vendor Name: BAXTER DIAGNOSTICS INC/SCIENTIFIC PRODUCTS
Address: 1430 WAUKEGAN RD
MC GAW PARK, IL 60085-6787 USA
Phone: 708/689-8410
Fax: 708/473-1397

6. Vendor Name: BRABENDER (C W) INSTRUMENTS INC
Address: 50 E WESLEY ST PO BOX 2127
SOUTH HACKENSACK, NJ 07606 USA
Phone: 201/343-8425
Fax: 201/343-0608
7. Vendor Name: BRINKMANN INSTRUMENTS INC
Address: ONE CANTIAGUE RD PO BOX 1019
WESTBURY, NY 11590-0207 USA
Phone: 516/334-7500, 800/645-3050
Fax: 516/334-7506, 516/334-7521
8. Vendor Name: BROOKFIELD ENGINEERING LABORATORIES INC
Address: 240 CUSHING ST
STOUGHTON, MA 02072-2398 USA
Phone: 617/344-4310, 617/344-4313, 800/628-8139
Fax: 617/344-7141
Telex: 200195, 924-497
9. Vendor Name: CANNON INSTRUMENT CO
Address: 2139 TECH RD PO BOX 16
STATE COLLEGE, PA 16804-0016 USA
Phone: 800/676-6232, 814/353-8000
Fax: 814/353-8007
10. Vendor Name: COLE-PARMER INSTRUMENT CO
Address: 7425 N OAK PARK AVE
NILES, IL 60714 USA
Phone: 708/647-7600, 800/323-4340
Fax: 708/647-9660
Telex: 28-9405
Cable: COLEPARMER

11. Vendor Name: CONAMETER CORP
Address: 9 DEMOCRAT WY
GIBBSBORO, NJ 08026 USA
Phone: 609/783-7675
Fax: 609/783-0675
12. Vendor Name: COOKSON AMERICA INC/ALPHA METALS INC
Address: 600 RTE 440
JERSEY CITY, NJ 07304 USA
Phone: 201/434-6778
Fax: 201/434-2307
13. Vendor Name: E L E INTERNATIONAL INC/SOILTEST PRODUCTS DIV
Address: 86 ALBRECHT DR PO BOX 8004
LAKE BUFF, IL 60044 USA
Phone: 708/295-9400, 800/323-1242
Fax: 708/295-9414
Telex: 687 1537 SOILT UW
14. Vendor Name: EMERSON ELECTRIC CO/ROSEMOUNT INC/ROSEMOUNT
ANALYTICAL INC/TEKMAR CO
Address: PO BOX 429576
CINCINNATI, OH 45242-9576 USA
Phone: 513/247-7000, 800/543-4461
Fax: 513/247-7050
Telex: 21-4221
15. Vendor Name: EXTECH INSTRUMENTS CORP
Address: 335 BEAR HILL RD
WALTHAM, MA 02154-1043 USA
Phone: 617/890-7440
Fax: 617/890-7864
Cable: EXTECH

16. Vendor Name: FALEX CORP
Address: 2055 COMPREHENSIVE DR
AURORA, IL 60505 USA
Phone: 708/851-7660
Fax: 708/898-7851
17. Vendor Name: FISHER SCIENTIFIC
Address: 711 FORBES AVE
PITTSBURGH, PA 15219 USA
Phone: 412/562-8300
18. Vendor Name: FISIONS INSTRUMENTS
Address: 55 CHERRY HILL DR
BEVERLY, MA 01915 USA
Phone: 508/524-1000
Fax: 508/524-1019(MARKETING)
Telex: 6819094
19. Vendor Name: FLUID DATA INC
Address: 2512 N VELASCO
ANGLETON, TX 77515 USA
Phone: 409/849-2344
Fax: 409/849-2166
20. Vendor Name: HUMBOLDT MANUFACTURING CO
Address: 7300 W AGATITE AVE
NORRIDGE, IL 60656 USA
Phone: 312/625-6321, 708/456-6300, 800/544-7220
Fax: 708/456-0137

21. Vendor Name: KALTEC SCIENTIFIC INC
Address: PO BOX 762
NOVI, MI 48376-0762 USA
Phone: 313/349-8100
Fax: 313/349-8909
22. Vendor Name: KOEHLER INSTRUMENT CO INC
Address: 1595 SYCAMORE AVE
BOHEMIA, NY 11716-1796 USA
Phone: 516/589-3800, 800/878-9070
Fax: 516/589-3815
Telex: 4973677 KOEHLER
Cable: "KOEHLER"
23. Vendor Name: LAB GLASS
Address: 1172 NORTH WEST BLVD PO BOX 610
VINELAND, NJ 08360 USA
Phone: 609/691-3200
Fax: 609/691-8588
24. Vendor Name: LAB-LINE INSTRUMENTS INC
Address: 15TH BLOOMINGDALE AVE
MELROSE PARK, IL 60160-1491 USA
Phone: 708/450-2600, 800/522-5463
Fax: 708/450-0943
25. Vendor Name: LEYBOLD VACUUM PRODUCTS INC
Address: 5700 MELLON RD
EXPORT, PA 15632-8990 USA
Phone: 412/327-5700
Fax: 412/733-5960

26. Vendor Name: LONGYEAR CO/BRAINARD-KILMAN DRILL CO
Address: 2175 W PARK CT PO BOX 1959
STONE MOUNTAIN, GA 30086 USA
Phone: 404/469-2720, 800/241-9468
Fax: 404/498-2841
27. Vendor Name: METTLER-TOLEDO INC
Address: 69 PRINCETON-HIGHTSTOWN RD PO BOX 71
HIGHTSTOWN, NJ 08520-0071 USA
Phone: 609/448-3000, 800/638-8537
Fax: 609/586-5451
28. Vendor Name: MILLIPORE CORP/WATERS CHROMATOGRAPHY DIV
Address: 34 MAPLE ST
MILFORD, MA 01757-9902 USA
Phone: 508/478-2000, 800/252-4752
Fax: 508/872-1990
Telex: 948413
CAGE: 20909+ 35819
SIC: 6630+
29. Vendor Name: NAMETRE CO
Address: 101 FORREST ST
METUCHEN, NJ 08840 USA
Phone: 908/494-2422
Fax: 908/494-8916
30. Vendor Name: NORCROSS CORP
Address: 255 NEWTONVILLE AVE
NEWTON, MA 02158 USA
Phone: 617/969-7020
Fax: 617/969-3260

31. Vendor Name: NORDSON CORP/FINISHING EQUIPMENT
Address: 555 JACKSON ST PO BOX 151
AMHERST, OH 44001 USA
Phone: 216/988-9411, 800/241-8777
Fax: 216/985-1417
Telex: 196109
32. Vendor Name: NORDSON CORP/PACKAGING PRODUCTS & ASSEMBLY
Address: 11475 LAKEFIELD DR TECHNOLOGY PARK/ATLANTA
DULUTH, GA 30136 USA
Phone: 404/497-3400
Fax: 404/497-3500
33. Vendor Name: RUSKA INSTRUMENT CORP
Address: 3601 DUNVALE PO BOX 630009
HOUSTON, TX 77263-0009 USA
Phone: 713/975-0547
Fax: 713/975-6338
Telex: 762-404
34. Vendor Name: SHIMADZU SCIENTIFIC INSTRUMENTS INC
Address: 7102 RIVERWOOD DR
COLUMBIA, MD 21046 USA
Phone: 410/381-1227, 800/477-1227
Fax: 410/381-1222
35. Vendor Name: UIC INC
Address: PO BOX 863
JOLIET, IL 60434-0863 USA
Phone: 800/342-5842, 815/727-5431
Fax: 815/744-1561

36. Vendor Name: WESTERN ATLAS INTERNATIONAL INC/CORE LABORATORIES
INSTRUMENTS

Address: 2015 MC KENZIE, STE 106
CARROLLTON, TX 75006 USA

Phone: 214/484-3431
Fax: 214/484-2070