In-Line Measurement of Electrical Properties for Flowing Dielectrics

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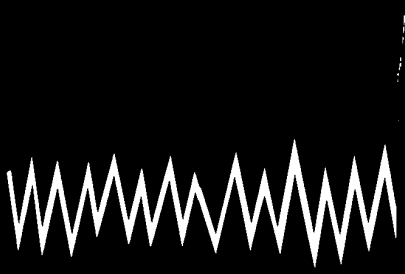

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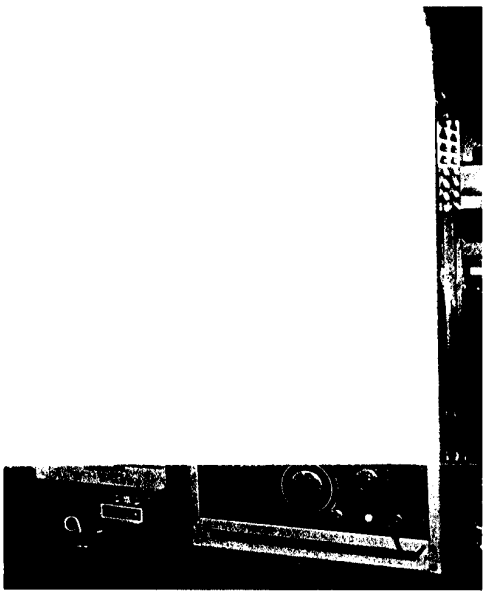
In-Line Measurement of Properties for Flowing

Introduction

Increasing quality demands on liquid dielectrics have necessitated improved refinement techniques and better methods of electrical property measurement. Recently, three-terminal electrical measurements with improved measuring sensitivity have been developed for laboratory measurements. However, factory needs went even further. Here, the desire was to have a quick, reproducible and reasonably accurate method of quality measurement. The equipment was to be rugged, mount directly on the process stream or be able to take off a small side stream, thereby eliminating the intricate sampling and sample handling methods normally employed for laboratory analysis.

Another feature desired was a direct readout which would be simple for the operating personnel and lend itself easily to recording.



Pictured here is the widely used two terminal laboratory system. Note that the sample requires considerable handling from the process to the actual measurement. The results are dependent on the sample handling.

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Electrical Dielectrics

Comparison Between the In-Line and Conventional Laboratory Measurements

The old two-terminal type measurement, a widely used laboratory standard in the past, has been recognized as inadequate to monitor the present high quality dielectrics. Improved 60Hz power factors produced have been beyond the measurement capability of this equipment. A more accurate three-terminal (guarded) laboratory system has been proposed which will overcome some of the inadequacies of the old method. Even with the improved technique, the results are dependent upon the sampling conditions, the container and the actual test conditions. Any laboratory sample is usually not too representative of the entire lot. Since the in-line analyzer processes a flowing side stream, the sampling difficulties are eliminated.

Cell cleaning, a very important part of the laboratory measurement, has not been demonstrated necessary on the in-line system, provided some discretion is exercised in the selection of the material passed through the analyzer system. This makes screening of material faster and easier. The in-line analyzer is not a substitute for the laboratory guarded measurement. It is, however, much faster and generally more suitable (for process monitoring) with reasonable accuracy. Compared to the two-electrode system, the in-line analyzer offers advantages by the elimination of lead cable effect and stray capacitance that give erroneous readings.

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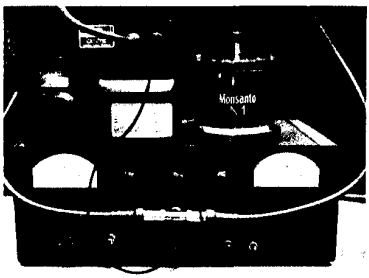
Recommended Use of In-Line System Equipment

RECOMMENDED USE OF
IN-LINE SYSTEM EQUIPMENT

The in-line analyzer system is recommended for usage in monitoring the electrical quality of askarels in process. Although resistance (DC) measurements can be made with the proper equipment, the preferred measurement is 100Hz power factor. This can be easily equated with measurements at other frequencies by the simple relationship shown in the calculations. The unit is designed to take the dielectric at 60°C, heat it to a measurement temperature of 100°C and make the measurement under flowing conditions. All this equipment is housed in one compact unit.



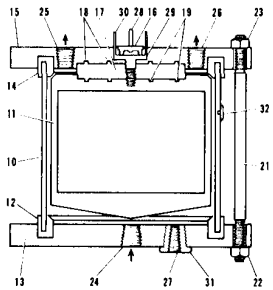
EQUIPMENT The in-line analyzer consists of three basic components (1) the cell, which is the heart of the entire operation, (2) a General Radio 1605AH Impedance Comparator which is the detector and (3) a General Radio Type 1422CB Precision Capacitor used as the standard for comparison.

CELL Basically, we use a three-electrode cell which provides a guarded electrode and permits highly accurate measurements because of the well defined area of the active electrode. More important still, lead effects are eliminated. The cell is highly polished 316 stainless steel using low conducting plastic insulators to separate the electrodes. The electrodes serve structural as well as electrical purposes.

The cell is designed to handle the dielectric under dynamic conditions with the outer electrode serving as part of the fluid housing. The guarded center electrode is designed to promote stability and uniformity in the fluid flow as it approaches the measuring zone. The end plate, designed to provide a seal for the cell, serves both as a connection to the system piping and as a guard electrode. A thermocouple is installed through the guard flange to measure the temperature of the fluid as it enters the measuring zone.

The cell is a Monsanto design (MONS)* specially built by Balsbaugh Laboratories in South Hingham, Massachusetts. The cell is designed for a total air capacitance of 75 picofarads.

MONSANTO IN-LINE CELL



NOMENCLATURE

10. Outside electrode (low)
11. Inner electrode (high)
12. Teflon insulator
13. Lower guard and bottom
14. Teflon insulator
15. Upper guard and top
16. Electrode screw and center contact
17. Teflon spacer
18. Viton (or Silicone) O Ring seal
19. Viton (or Silicone) O ring seal
21. Support bolts and guard connection
22. Lower lock nut
23. Upper lock nut
24. Fluid inlet
25. Fluid outlet
26. Fluid outlet
27. Insert hole for thermocouple
28. Inner electrode terminal on GR 874 plug
29. Kel F insulator washer
30. Guard connector to GR 874 plug
31. Teflon insulator for ⅛" tube X ⅛" NPT pipe
32. Outside electrode terminal

*Patent pending

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Measuring Equipment

Test equipment used with the specially designed cell is a General Radio 1610 AH Impedance Comparator with a General Radio Type 1422CB Precision Capacitor for the dissipation factor measurements. (Note: Due to the small error the dissipation factor is read directly as Power Factor. See relationship shown in the calculations.)

Measurements are made at 100Hz and 100 C. Since the GR1605AH is a comparator, a small correction for the power factor on the GR1422CB Precision Capacitor is necessary for maximum precision, but in most cases it can be ignored. Also, being a comparator, higher power factors can be measured by simply adding resistance on the known side. Because the 1605AH is a transformer ratio arm bridge, and guarded (3 terminal) measurements are made, the cable effect is eliminated. Therefore, knowing the air capacitance of the empty cell, it is possible to monitor the dielectric constant as well as the power factor. (See calculations)

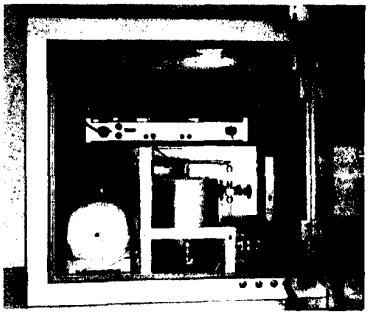
Auxiliary Equipment

The GR1605AH Impedance Comparator is direct reading for power factor and capacitance balance. However, a jack is provided at the rear of the instrument for recording. A ±5 MV signal is supplied for driving the recorder. Most recorders are connected only to the power factor indicator for quality monitoring. One such recorder used on this system has been a Leeds and Northrup Model 15.

Another electrical quality measurement is the specific resistance or resistivity. By the use of a General Radio 1644A Megohm bridge, periodic resistance measurements can be made. These measurements do not lend themselves well for continuous quality surveillance. However, since resistivity is regarded by many people as a measure of quality, it is desirable to be able to make such measurements for comparison.

For the 50Hz application, modifications must be made to the bridge components to eliminate harmonic problems causing beeps in the test results.

The component parts are mounted in an enclosed case which is nitrogen purged. The case contains a sample heater with sufficient control equipment to bring the material to the measurement temperature. Included is a temperature and flow indicator for adequate control. Process connections are provided at



the rear of the instrument along with the nitrogen purge connection. All power for the instrument is provided by the 110-120 VAC plug. The instrument is thoroughly grounded to the ground lead of the plug. Therefore, any auxiliary connection must be well grounded.

The instrument is connected to a bypass side stream for process monitoring. The flow is set at 5 gph and the system is allowed to reach the operating temperature of 100 C as shown on the indicator. Once the system reaches temperature equilibrium and the liquid flushes the cell, the sensitivity of the instrument is adjusted until a reading can be made with the maximum sensitivity. The capacitance balance is made by adjusting the precision capacitor until a null is obtained on the "Impedance Difference" meter.

Once the instrument reaches steady state operation, the power factor is indicated on the "Phase Angle Difference" meter and recorded if an auxiliary recorder is attached. As the power factor improves and the reading lowers, the sensitivity should be increased for maximum accuracy.

The instrument can be started or stopped by merely closing off the flow. There are automatic cut-offs in the bridge to prevent damaging the instruments on overrides. The temperature control has a built-in system to prevent thermal degradation of the dielectric, so when the flow undergoes major upsets, steady state temperature control will not be regained immediately. Flow rates exceeding the meter range may result in erroneous readings.

DISCUSSION OF MEASUREMENT

As previously discussed, the in-line measurements are guarded. To maintain the guard and keep the flow-through characteristics, teflon connectors are used on the inlet and outlet of the cell. The fluid is heated slightly above 100°C by an electrical heat exchanger, which controls the watt density heating the

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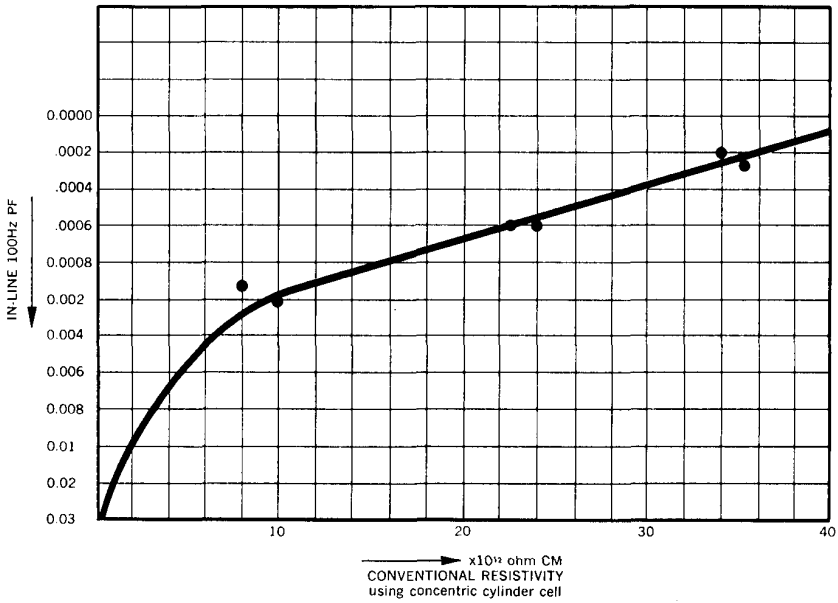
sample. The fluid temperature is measured directly before it enters between the measuring electrodes.

The system is also designed for streamline flow between the electrodes. All eddies or pockets are eliminated in order to obtain a steady reading. Once the electrical measurement is made, the sample is returned to the process. All handling of the fluid is in a closed system to eliminate contamination. With the other precautions built into the in-line system, an accurate reproducible electrical quality measurement can be made.

Calibration of the In-Line System Against Present Standard

To arrive at a smooth transition between the present standard (regardless of electrode configuration or test equipment), the presently used standard must be calibrated against the in-line readings. One such comparison between the conventional two-electrode system and the in-line anlyzer is shown in the graph (based on resistivity).

IN-LINE POWER FACTOR vs CONVENTIONAL RESISTIVITY.



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Theoretical Relationship In Electrical Measurements

Relationship Between Power Factor (PF) and Dissipation Factor (D)

$PF = \frac{D}{\sqrt{1 + D^2}}$ Since D is small, $PF = D$

Determination of Resistivity (P)

$P = \frac{A}{t} R_V$

R_V = volume resistance, in ohms, measured on GR 1644 Megohm bridge

$\frac{A}{t} = \frac{C_A}{E_0}$ *see relationship between capacitance C and surface-gap of cell $\frac{A}{t}$

(Based on actual measurement of C_A for each cell)

$\frac{A}{t} = \frac{75 \times 10^{-12} \text{ farads}}{8.85 \times 10^{-12} \text{ (coulomb)}^2/\text{Newton M}^2}$

$\frac{A}{t} = 8.45$ M or 845 cm

Theoretical Relationship for Power Factor (PF) and Resistivity (P)

$PF = -\frac{1}{\omega R_P C_P}$

$R_P = R_V$ = volume resistance

where $R_V = P/A/t$

C_P = parallel capacitance

ω = (sinusoidal wave shape assumed)

$= 2\pi f$

where f = cycles per second

$PF = \omega R_S C_S$

R_S = series resistance

C_S = series capacitance

Relationship Between Capacitance (C) and Surface-gap of Cell (A) (t)

$C_A = E_0 \frac{A}{t}$

C_A = air capacitance

E_0 = permitivity of free space or vacuum 8.854×10^{-12} coulombs^2/ (Newton) $(M)^2$

A = average area between the electrodes

t = space between the electrodes

Determination of Dielectric Constant (K)

$K = \frac{C_x}{C_A}$

C_x = capacitance of sample

C_A = capacitance of air

Frequency Correction for PF

$PF_x = \frac{fm}{f_x} PF_m$

PF_m = measured power factor

fm = measuring frequency

f_x = desired frequency for measurement

Comparison Between Physical Measurements and Calculation from the Electrical Measurements

Physical Measurement

$\frac{A}{t} = 835$ cm

Calculation

See Determination of Resistivity

$\frac{A}{t} = \frac{C_A}{E_0}$

$= 8.45$ M or 845 cm

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