cooperative panel could be set up and a large number of samples could be studied statistically, the carbonyl index may help to establish a standardized scale for evaluating the reverted and rancid odor of edible oils.

Summary

The amount of volatile carbonyl compounds diffused from 100 g. of an oil into a stream of nitrogen bubbled through the oil under specified conditions was determined by converting the carbonyl compounds into their 2,4-dinitrophenylhydrazones and then measuring the absorption of the wine-red color of the quinoidal ions at 480 mμ. From the absorbance thus obtained, a carbonyl index was calculated and assigned to the oil.

The carbonyl indices of a number of edible oils, such as soybean, cottonseed, and hydrogenated vegetable, were found to correlate with the degree of reversion and rancidity of the oils as determined by organoleptic means. The reproducibility of the carbonyl index determination was 3%. This accuracy corresponded to approximately $\pm$ 0.1 point in an organoleptic testing panel in which 1 point represented a very unacceptable oil and 10 points a very good oil. The carbonyl index method may also be used as a means of evaluating the flavor stability of edible oils. The carbonyl index gave a good indication of the flavor stability after aging at 60°C. for the less stable and 100°C. for the more stable oils and fats.

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Development of Buckeye Continuous Moisture Meter for Oil-Bearing Materials[1]

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THE NEED for rapid accurate moisture determinations in the oil milling industry has long been recognized. This has been partially met by electric moisture meters which indicate the moisture content on single samples. Their speed and simplicity permit plant operators to make frequent tests and to improve moisture control. However certain disadvantages remain. Mill operators are not always sufficiently careful to take representative samples, operate the instrument carefully, and determine temperature and readings accurately. Obvious advantages would be obtained by a meter installation which would automatically and continuously sample the material and determine and record the moisture content. A continuous record which shows trends is greatly superior to single tests at intervals.

The development of a continuous moisture recorder has paralleled that of the batch type in the Buckeye Cotton Oil Company. Six years were required to carry theory into design and to field-test the instruments until a successful model was evolved. As it is an asset in the processing of oil seeds, the Buckeye Cotton Oil Company wishes to make the meter available to the industry.

Theoretical Considerations

A. *Moisture Detection and Recording*

A continuous recording moisture meter consists of three parts:

1. The detection circuit which measures a change in a characteristic of the material which is dependent upon its moisture content.
2. The test cell through which a stream of the material flows.
3. The recorder which translates the signal from the detection circuit to a chart or graphic record.

Detection Circuit. In developing the batch type meter it was found that the dielectric constant of vegetable oil materials varied with the moisture content, also that it was possible to compensate for other influencing variables as their effects upon the dielectric constant are consistent and measurable.

As the basic considerations in the measurement of the dielectric constant have been discussed in a preceding paper, "Development of the Buckeye Moisture Meter for Use on Oil-Bearing Materials," they will not be repeated.

Test Cell. The primary problem in developing a continuous meter was the design of a test cell through which the sample flows. A cylindrical cell was chosen as it would be self-cleaning and more uniformly filled by a flowing sample. Also the test cell must be a precision electrical condenser; cylindrical design tends to eliminate edge effects. Three types were considered: a) coaxial design consisting of two cylindrical electrodes of different diameter; b) single tube split lengthwise, the two halves forming the two electrodes, being mounted on a non-conducting tube; c) a non-conducting cylinder wrapped spirally with two strips of metal spaced equidistant at all points.

The dimensions of the test cell were calculated for coaxial design and determined experimentally for the other types.

Recording Instrument. The recording instrument must translate the signal from the detection circuit to a graphic record indicating percentage of moisture. There are a number of manufacturers of suitable recorders. The choice depends upon the type and magnitude of the signal, the range, and required speed of response to signal changes.

B. *Compensation for Variables Other Than Moisture.*

Temperature compensation must be built into the circuit of a continuous meter. It was neces-

[1] This paper covers work carried out by the A. D. Little Company under contract C-57803 in 1947 and 1948 with The Buckeye Cotton Oil Company. It also covers Buckeye investigations carried out since 1930. The paper was presented at the fall meeting of the American Oil Chemists' Society, Cincinnati, O., in October, 1952.

sary to determine if automatic compensation is practicable and reliable.

Density also requires compensation. As this is not conveniently measured, it was necessary to maintain constant density in loading the test cell.

Development Work

Development of the continuous moisture meter was conducted in two phases. Arthur D. Little Inc. was retained to work with the Buckeye Technical Division on the design, construction, and testing of a continuous meter. Independently the Buckeye Cotton Oil Company was adapting the Buckeye batch type meter to use as a continuous meter.

A. *Work with Arthur D. Little Inc.*

After an extensive literature survey (1-39) the dielectric constant was chosen as the measurable characteristic varying with the moisture content. Its use had been confirmed by results obtained over a number of years with the Buckeye batch dielectric type meter.

The instrument for measuring and recording changes in the dielectric constant was developed and built by the Foxboro Company. With information on the sensing cell furnished by Arthur D. Little Inc. the Foxboro Company designed a capacity-operated Dynalog recorder as part of the complete continuous moisture meter.

The test cell was designed as a precision condenser through which the material to be tested flows. The capacitance of this cell, or condenser, changes with the change in the dielectric constant of the material. The final cell design consisted of two concentric cylinders acting as the two electrodes of the condenser. The coaxial design is superior electrically because it presents a more uniform flux pattern with minimum edge effect. The basic capacitance of this type cell is calculated from the formula:

$$C = \frac{(2.83)(K)(l)}{\ln(b/a)}$$

C = capacitance in micro farads
l = length in inches
K = dielectric constant for medium between electrodes (1.0 for air)
b = radius of outer electrode
a = radius of inner electrode

The dimensions of the test cell were governed by the requirements of the Foxboro Dynalog recorder. It was necessary for the sensing unit to have an output of at least 5 m.m.f. to the recorder for full scale deflection. The final test cell design is shown schematically in Figure 1. The dimensions were:

Length—13 inches
Outer tube—3 in. O.D., $\frac{1}{16}$ in. wall thickness
Inner tube—1 in. O.D., .032 in. wall thickness

Automatic compensation for temperature change was developed next. The effect of temperature range on the dielectric constant and loss was determined on soybean meal and protein, and on cottonseed meats and flakes. Figure 2 shows test cell capacitance changes due to moisture and temperature variation in a sample of extracted soybean meal. Arthur D. Little furnished this graph to the Foxboro Company. Foxboro developed a device which compensates for temperature change over the normal range of moisture and temperature. For soybean meal 80°-160°F. with moisture 10-13% was considered adequate.

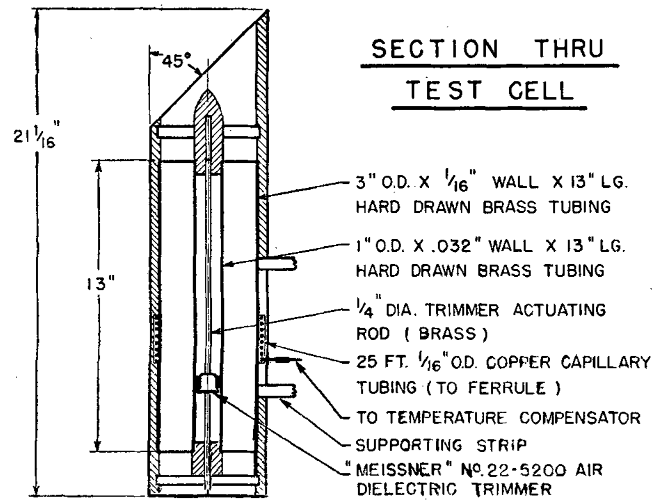


FIG. 1

The temperature compensation device developed by Foxboro consists of two parts:

1. The series capacitor (padding condenser) is placed in the test cell between the center electrode and the hot r.f. lead. This condenser serves to compensate for the essentially linear variation of the reactive component of the capacitive impedance and serves to make the slope of the curves of the reactive component *vs.* moisture the same at all temperatures.
2. With the compensation accomplished, the temperature effect then becomes merely a shifting of the curve up and down the reactive component axis an amount directly proportional to the change in temperature. This displacement is compensated for by the use of an air condenser which is placed in parallel with the test cell.

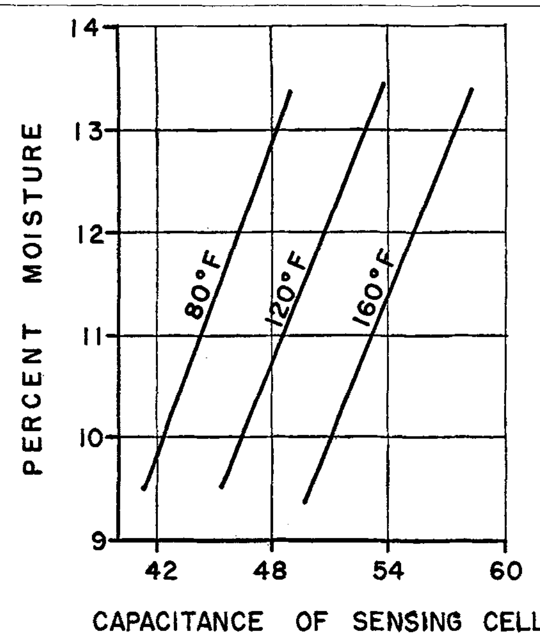


FIG. 2. Effect of temperature and moisture on capacitance of 3" dia. x 13" condenser with 75 mmfs padding condenser when filled with extracted soybean meal.

This condenser is positioned by means of a liquid-filled thermal expansion system, the sensing bulb of which is a length of 1/16 in. O.D. copper tubing which is wrapped around the outer electrode.

The remaining problem was to obtain a uniform flow of the material through the test cell so that density would be practically constant. Field tests showed that a short free fall of the material into the test cell, in amount slightly excessive to keep the cell full, gave adequate density control.

It was also necessary to keep the material flowing through the cell at a uniform rate to overcome pulsating response. The method developed is shown in Figure 3, which provides a rapid flow through the test cell, preventing bridging or clogging.

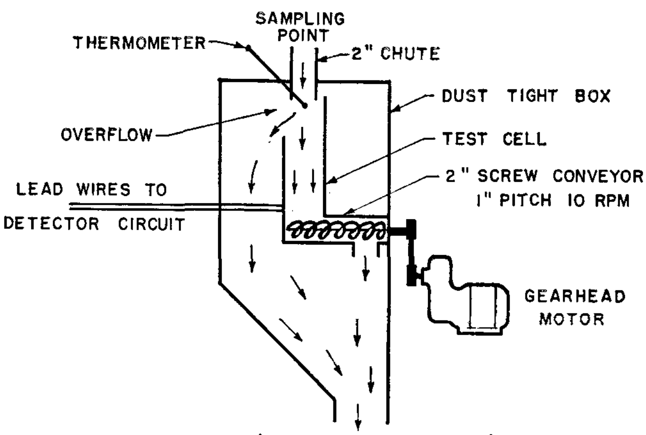


FIG. 3. Schematic illustration of installation of test cell for continuous moisture meter.

B. *Buckeye Meter Adapted to Continuous Service*

Independently of the above work with Arthur D. Little Inc., effort was made to adapt the Buckeye batch type meter to continuous use.

Split cylinder and concentric types of cells were unsatisfactory. A spiral wound cylinder was successful. This is a 2-in. I.D. Bakelite cylinder 10 in. long spirally wound with 3/4-in. wide copper ribbon. Ribbons are spaced 3/4 in., extend around 6 in. on the cylinder length, and are held in place with electrical Scotch Tape. The cell was mounted with a 2-in. double flight screw conveyor, 10 r.p.m., at the bottom to discharge the cell.

The detection circuit is essentially that of the batch meter except that temperature compensation was added. The circuit is shown in Figure 5. Temperature compensation is by manual adjustment. A 50 m.m.f. variable condenser between the "hot" cell lead and chassis ground permits adjustment of the capacitance effect of the cell. Temperature change effect is greater at higher levels; this is overcome by hand trimming the condenser so it can be calibrated directly in terms of sample temperature.

The 01-MA indicator of the batch meter was replaced with an 01-MA recording type. A Leeds and Northrup was found satisfactory.

Installation and Operation of Meters

The two continuous meters were tested under similar conditions. Figure 3 shows the typical installa-

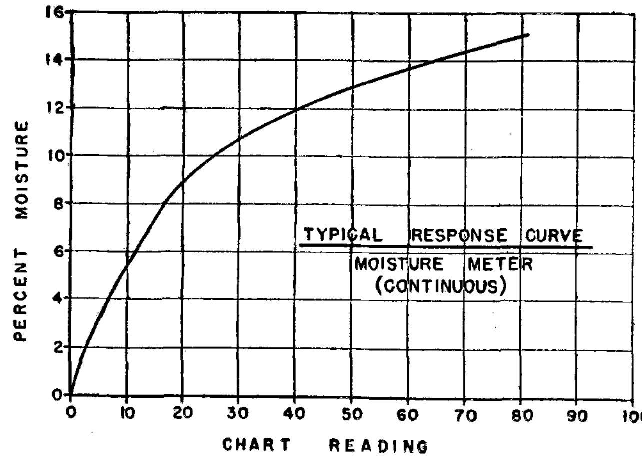
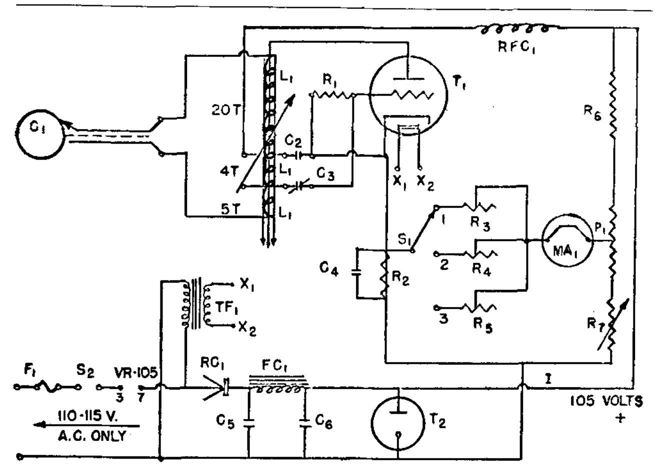


FIG. 4

tion. The test cell is placed in a dust-tight box. The sample flows in through a 2-in. pipe, adjusted to overflow the cell. Detection and recording equipment was installed close by. Temperature is obtained by a thermometer in the stream.

The unit developed with Arthur D. Little Inc. required no attention except to start sample flow and conveyor, and turn on 115 R.A.C. power to the Foxboro recorder. However inspection is made for the possibility of clogging.

For the converted Buckeye batch meter, installation and operation are the same except that temperature is read at intervals and the temperature com-



C1 - MOISTURE CAPACITOR, .005" BRASS SHIM STOCK 5/8" WIDTH, 4 7/8" LENGTH.
L1 - OSCILLATING COIL BUILT ON 3/4" FORM WITH VARIABLE SLUG.
C2 - .01 MFD, 200 VOLT CONDENSER.
C3 - 100 UU FD, CONDENSER.
C4 - 0.1 MFD CONDENSER.
C5 - 10 MFD CONDENSER.
C6 - 10 MFD CONDENSER.
R1 - 470 M Ω RESISTOR, 1/2 W
R2 - 500 Ω, 1/2 W RESISTOR.
R3 - 6000 Ω, 1 W RESISTOR.
R4 - 6000 Ω, 1 W RESISTOR.
R5 - 6000 Ω, 1 W RESISTOR.
R6 - 30000 Ω, 2 W RESISTOR.
R7 - 1000 Ω, 2 W VARIABLE RESISTOR.
P1 - 200 Ω, 2 W POTENTIOMETER.
MA1 - 0-1 M AMPERES, PLATE METER.
T1 - 6J5 TUBE.
T2 - VR - 105 TUBE.
FC1 - 8 MH
RFC1 - RF CHOKE, 2.5 MH
RC1 - HALF WAVE RECTIFIER.
TF1 - FILAMENT TRANSFORMER 6.3 VOLTS.
S1 - A-81 SWITCH.
S2 - LINE SWITCH.
F1 - AG 3 BUSS FUSE
COAXIAL CABLE - TYPE RG 59 U

FIG. 5

Moisture Content S/B Meal	After Meter Installed	
	No. Cars	% of Cars
Below 10%	14	2.3
10.1–10.5	24	3.9
10.6–11.0	142	23.2
11.1–11.5	212	34.4
11.6–12.0	191	31.0
12.1–12.5	32	5.2
Over 12.5%	0	0
Total No. Cars	615	
Cars Within Standards Cars 11.5 ± 0.5%	491	80%
Aver. % H_2O in Meal		11.4

pensator is adjusted. As the material temperature changes infrequently, this is not burdensome.

Results

The completed meter was installed in a soybean mill where irregular meal production caused wide moisture variation up to 4% in 20 min. Before installing the meter, 41% of meal shipments were outside the desired moisture limits despite supervision effort. With the continuous meter the number outside of limits was reduced to 20%, as shown in the following table. A typical response curve on solvent soybean meal is shown in Figure 4.

Continuous recording meters have been installed in a number of soybean plants, effecting a 33% reduction in standard deviation of moisture content. The meter also reduces the work of the operators and gives supervisors helpful record for reference. Further tests indicate that the meter may be successfully used on all materials which will flow uniformly through the test cell and have a moisture range between 8 and 16%.

Summary

A continuous recording moisture meter was needed in processing oil-bearing seed materials. Two successful meters, similar in principle but different in design, have been developed.

Theoretical considerations involved in designing such a meter are presented, with circuit diagrams and descriptions of test cells. The work with Arthur D. Little Inc. is reviewed, also the independent development by the Buckeye Cotton Oil Company.

Continuous moisture meters are valuable aids in plant operation greatly improving moisture control in soybean meal and saving operator time. Their value is in the plant; they do not have the accuracy of a laboratory instrument.

The continuous moisture meters described are presented to the industry for their demonstrated value and superiority over batch-type meters.

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