PHYSICOCHEMICAL MEASUREMENTS

ANALYSIS OF DYNAMIC ERRORS IN AUTOMATIC
ABSORPTION METERS AND REFRACTOMETERS

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Automatic absorption meters and refractometers intended for analyzing liquid media are widely used in industry. It is known that according to the law of Bouguer-Lambert-Beer the concentration of the dissolved substance in absorption meters is proportional to the optical density of the solution and is determined by the change in the intensity of a monochromatic radiation which has passed through a layer of the tested liquid.

The differential prism method is the one most widely used in automatic refractometers intended for testing liquids. The bulb (Fig. 1) of such instruments consists of two parts, comprising a flow-through part with a circulating liquid whose refractive index is \( n \) and a closed part which contains a liquid with the known refractive index \( n_{cp} \) and is immersed into the flow-through part in order to establish thermal balance. The deflection of the light beam which emerges from the bulb is proportional to the difference \( \Delta n = n - n_{cp} \).

The deviation angle represents the instrument's statistical characteristic and is determined from the formula [1]

\[
\beta = \Delta n \cdot \tan \gamma,
\]

where \( \gamma \) is the angle between the incident beam and the perpendicular to the boundary between the flow-through and the closed parts of the chamber.

Automatic refractometers measure the relative refractive indexes of liquids and they are mostly used for testing binary mixtures. Their principle of operation is shown in Fig. 2. The conveying link CL consists of the length of pipe from the sampling point of the tested liquid to the instrument's input stub pipe (sampling device) and from the input stub pipe to the bulb.

It has been noted above that in absorption meters the parameter of the liquid which flows continuously through the bulb (the bulb converter BC) is converted into variations of the luminous beam intensity, whereas in refractometers it is converted into a beam deflection. In both cases this leads to an unbalance of a photoelectric transducer PET. The unbalance voltage is transmitted through the amplifier A to the control winding of the reversible motor RM which drives the compensator K until balance is reestablished. The aggregate of elements PET, A, RM, and K constitutes the measuring transducer MT. The compensator's function in absorption meters is performed by an optical wedge and in refractometers by a mechanical displacement of the photodetector. Let us examine the dynamic properties of elements. Element CL is characterized by the conveying retardation time \( \tau \) which is accounted for in the output signal function as

\[
y(t) = \begin{cases} 
0 & \text{for } 0 < t < \tau \\
x(t - \tau) & \text{for } t > \tau.
\end{cases}
\]

The transfer function of such elements is represented by the relationship

\[
W_{cl}(p) = e^{-pt},
\]

where \( p \) is the Laplace operator.


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The bulb of an automatic flow-through absorption meter or refractometer consists of a vessel with stub pipes for the inflow and outflow of the tested liquid. The transfer function of the bulb is determined from the material balance equation of such devices as

\[ \frac{dy}{dt} = \frac{Q}{V} (x - y), \]  

whence

\[ W_{bc}(p) = \frac{y_1(p)}{x(p)} = \frac{K_{bc}}{T_{bc} p + 1}, \]

where \( x \) is the input signal of the bulb changes in the concentration of the tested liquid), \( y_1 \) is its output signal (changes in the intensity of radiation in absorption meters and of the beam deviation in refractometers), \( K_{bc} = y_1(t)/x(t)_{t \to \infty} \) is the transfer factor of the bulb converter, \( T_{bc} = V/Q \) is the bulb converter's time constant which consists of the ratio of the volume \( V \) to the flow \( Q \) of the liquid (without accounting for the mixing conditions).

The MT transfer function, without accounting for the time constant of the amplifier and the electromechanical constant of the reversible motor, has the form of [2]:

\[ W_{mt}(p) = \frac{y(p)}{y_1(p)} = \frac{K_{ts}}{T_{ts} p + 1}, \]

where \( y(p) \) is the output signal of the tracking system and the instrument as a whole, \( K_{ts} = y(t)/y_1(t)_{t \to \infty} \) is the transfer factor of the tracking system, \( T_{ts} \) is the time required for a complete revolution of the motor axle at the maximum processing speed of the unbalance signal equal to the full scale deflection.

The transfer function of the instrument as a whole is

\[ W_t(p) = W_{cl}(p) \cdot W_{bc}(p) \cdot W_{mt}(p) \]

or after substituting for \( W_{cl}(p) \), \( W_{bc}(p) \), and \( W_{mt}(p) \) their values from (2), (4), and (5) it becomes

\[ W_t(p) = \frac{y(p)}{x(p)} = \frac{K_{t} e^{-\beta \tau}}{(T_{bc} p + 1)(T_{ts} p + 1)}, \]

where \( K_t = K_{bc} \cdot K_{ts} = y(t)/x(t)_{t \to \infty} \) is the transfer factor of the instrument as a whole.

The transfer function of the refractometers bulb and of the entire instrument are represented by Eq. (4) and (6), provided that the temperature of the tested liquid remains constant. Temperature variations produce considerable changes in the refractive index of the tested liquid. Moreover, the temperature and the refractive index of the liquid in the closed part of the bulb change correspondingly; thus producing the dynamic error \( \xi \) (Fig. 3) whose value and nature depend on the instrument's dynamic parameters [3].

Since the dynamic error is formed in a similar manner to the measurement signal, the instrument's static temperature characteristic (error) can be represented, with (1) taken into account, by the expression

\[ \delta_t = b \cdot \Delta \Theta, \]