Uncertainty of Measurement alcohol concentration with Evidential breath analysers

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***Abstract*— Evidential breath analysers are used to determine the alcohol concentration of motor vehicle drivers and are subject to legally defined metrological control. The legislator has provided for a coercive administrative measure and administrative penalties for those who violate the traffic rules. The main argument in the appeal of the act imposing the measures and punishments is the measured values of the alcohol concentration by the breath alcohol analyser. The purpose of the report is to present the accuracy and sources of uncertainty in the measurement of alcohol concentration with breath alcohol analysers.**

Keywords—Evidential breath analysers, alcohol concentration, metrological control, uncertainty budget

I. INTRODUCTION

The United Nations (UN) has proclaimed the period 2021-2030 as the Decade of Action for Road Safety. The Council of Ministers, with its Decision 775, adopted a National Strategy for Road Traffic Safety in the Republic of Bulgaria for the period 2021-2030, as well as an Action Plan 2021-2023, aiming to achieve the ambitious goal of preventing at least 50 % of road deaths and injuries by 2030 [1]

Speeding and drink driving are considered to be major factors in road deaths. Therefore, in the last decade and in the coming one, measures and actions to reduce death in this area as much as possible are being prioritized.

The driver of a road vehicle is obliged not to drive a road vehicle under the influence of alcohol, drugs or other intoxicating substances. The legal limit of permissible blood alcohol concentration for Bulgaria is 0,5 ‰. [2].

Despite the legislator's desire to regulate the rights and obligations of citizens in order to protect their life and health and ensure road safety, many road users ignore these legislative frameworks and, succumbing to their own needs, often violate road safety rules. This irresponsible behaviour of road users leads to the high statistics of death on the road, as well as economic losses from material damages that occur as a result of the numerous traffic accidents.

The legislator has provided for a coercive administrative measure and administrative penalties for those who violate the traffic rules.

The right to defend oneself and to prove one's right in a court of law given to us by the Constitution of the Republic of Bulgaria [3] gives the opportunity to challenge the results of measuring the alcohol concentration with breath alcohol analysers, to many road users who allowed themselves to violate the legally established rules of road traffic, namely to drive with the presence of an unacceptable concentration of alcohol in the blood.

Ensuring the accuracy and reliability of the measurement results of breath alcohol analysers is carried out through metrological control in accordance with the Law on Measurements and the normative acts on its implementation. The periodicity of inspections is six months.

The main metrological characteristic that is evaluated when performing testing for the purpose of type approval or verification of breath alcohol analysers is the measurement error. Every measuring instrument has its error, and every measurement result its uncertainty.

The task is to determine the sources of uncertainty in the measurement of alcohol concentration with breath alcohol analysers.

II. ESTIMATIING OF CONTRIBUTIONS TO THE MEASUREMENT UNCERTAINTY OF EVIDENTIAL BREATH ANALYSERS ALCOHOL CONCENTRATION

A. Evaluation the contributions of uncertainty of measurment

A mathematical model forming the budget of uncertainty in the measurement of alcohol concentration with breath alcohol analysers, the components of this uncertainty and their calculation and combination has been compiled.

For this purpose, a study was carried out to identify the influencing input variables. As a result of the research and analysis, the following sources influencing the measurement uncertainty were identified:

- The determined values and associated uncertainties of a certified reference material (CRM), mg/l;
- Maintaining the recommended temperature values in the measurement process;
- The use of equations containing constants;
- The resolution of the relevant type of measuring instruments.

Two types are used to evaluate the measurement uncertainty components type A and type B. Type A evaluates the measurement uncertainty components by statistical analysis of the measured values of the quantity obtained under certain measurement conditions. While type B evaluates the measurement uncertainty components in a different way than type A or:

- Associated with a CRM quantity value,
- Received from a calibration certificate,
- Pertaining to drift,

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- Obtained from an accuracy class of a verified measuring instrument,
- Obtained based on personal experience.

B. Mathematical model of measurement

The output quantity in the measurement model is the measured quantity Y whose value must be obtained from the information about the input quantities in the measurement model X_i = ($i=1,2,\ldots N$) in accordance with a functional dependence.

$$Y = f(X_1, X_2, \ldots, X_N) \tag{1}$$

Evaluation the measured quantity Y, the output estimate, denoted y, is obtained from equation (1) using input estimates xi for the values of the input quantities X_i

$$y = f(x_i) + f(x_r) + f(x_{CPM}) + f(x_t) \tag{2}$$

where:

y – evaluation of output quantity;

x_i - input value evaluation - breath alcohol analyser readings;

x_r - evaluation of the input quantity – resolution of the breath alcohol analyser;

x_{CPM} - evaluation of the input quantity - uncertainty of CRM;

x_t - assessment of the input value - temperature of solution and test gas;

Type A evaluation of measurement uncertainty:

Type A evaluation of measurement uncertainty is applied to independent observations of an input quantity under identical measurement conditions. The value of mass concentration of ethanol measured under repeatability conditions is estimated by the arithmetic mean value of n independent readings of the measured quantity by the evidential breath analysers.

$$\overline{x_{\mathrm{i}}} = \frac{1}{n} \sum_{\mathrm{j}=1}^{n} x_{i,\mathrm{j}} \quad , \ n \geq 10 \tag{3}$$

Standard measurement uncertainty is expressed as standard deviation. The estimate of the standard deviation of the distribution of values $x_{i,j}$ is determined by the formula (4)

$$S(x_{\mathrm{i}}) = \sqrt{\frac{\sum_{\mathrm{j}=1}^{n} (x_{i,\mathrm{j}} - \overline{x_{\mathrm{i}}})^2}{(n-1)}} \tag{4}$$

The evaluation of the standard deviation of the arithmetic mean is represented by a formula (5):

$$S(x_i) = S(\overline{x_i}) = \frac{S(x_i)}{\sqrt{n}} \tag{5}$$

The standard uncertainty of the input quantities is calculated $u\ (x_N)$.

The standard uncertainty of the measured quantity $u\ (x_i)$ when performing n independent measurements, which are characterized by a normal distribution, it is calculated according to the equation:

$$u(x_i) = u(\overline{x_i}) = S(\overline{x_i}) \tag{6}$$

If the number of independent measurements n < 10 must be taken into account the reliability of evaluation the standard uncertainty type A or

$$u(x_i) = h.S(x_i) \tag{7}$$

Where h is a sensitivity coefficient that depends on the number of measurements n.

Table 1 shows the dependence of the sensitivity coefficient on the number of measurements.

TABLE I. CENSITIVITY COEFICIENT h

Number of single measured values, n	**Sensitivity coefficient, h**
2	7
3	2,3
4	1,7
5	1,4
6	1,3
7	1,3
8	1,2
9	1,2
10	1

In the case when n ≥ 10 за $u(x_i)$ a formula is applied (8)

$$u(x_{\mathrm{i}}) = \sqrt{\frac{\sum_{\mathrm{j}=1}^{n} (x_{i,\mathrm{j}} - \overline{x_{\mathrm{i}}})^2}{n(n-1)}} , \tag{8}$$

Type B evaluation of measurement uncertainty:

Type B evaluation of measurement uncertainty is the method of estimating the uncertainty associated with an estimate x_i of the input quantities *Xi*, by means other than statistical analysis of a series of independent observations. The standard uncertainty $u(x_i)$ is empirically estimated based on all available information about possible changes in *Xi*. The data belonging to this category can be extracted from the thermometer calibration certificates and the CRM certificate.

The standard uncertainty of the certified reference material is calculated by the formula:

$$u(x_{CPM}) = \frac{U(x_{CPM})}{2} \tag{9}$$

where:

$U(x_{CPM})$- expanded measurement uncertainty given in the certificate of CPM.

Uncertainty related to the temperature of mass concentration of ethanol is calculated by the formula:

$$u(x_t) = \frac{C_{34+Ut/2} - C_{34-Ut/2}}{\sqrt{3}} \tag{10}$$

where:

C_{34} - mass concentration of ethanol at t=34°C.

U_t – expanded uncertainty given in the thermometer calibration certificate.

Uncertainty related to the resolution of the evidential breath analysers:

$$u(x_r) = \frac{r}{2\sqrt{3}} \qquad (11)$$

where:

r – resolution or the smallest change in the magnitude read by the evidential breath analysers

Estimation of combined standard measurement uncertainty:

The quantity $u_i(y)$ is the contribution to the standard uncertainty associated with the output estimate *y* obtained from the standard uncertainty associated with the input estimate x_i:

$$u_i(y) = c_i\, u(x_i) \qquad (12)$$

Where c_i is the sensitivity coefficient associated with the input estimate x_i

$$c_i = \frac{\partial f}{\partial x_i} = \frac{\partial f}{\partial X_i}, \qquad (X_1 = x_1, \dots, X_N = x_N) \qquad (13)$$

The combined standard uncertainty of the measured is defined as the positive square root of the sum of the variances of the input quantities.

$$u_c(y) = \sqrt{u_i(y)^2 + u(y_r)^2 + u(y_{CPM})^2 + u(y_t)^2} \qquad (14)$$

The expanded uncertainty for each measured value is expressed as

$$U = k . u_c(y) \qquad (15)$$

where:

$u_c(y)$ - combined standard uncertainty

k- coverage factor.

Expanded uncertainty product a combined standard measurement uncertainty and a coverage factor *k*=2 which, for a normal distribution, corresponds to a level of confidence of approximately 95%.

Estimating the effective degrees of freedom V_{eff}

The reliability of the standard uncertainty attributed to the output estimate is determined by its effective degrees of freedom. Determine the effective degrees of freedom V_{eff} of the standard uncertainty *u(y),* associated with the output estimate *y* from the Welch–Satterthwaite formula is given as follows:

$$V_{eff} = \frac{u^4(y)}{\sum_{i=1}^{N} \frac{u_i^4(y)}{v_i}} \qquad (18)$$

where:

u(y) - combined standard uncertainty;

$u_i(y)$, where $i=1, 2, \dots n$ - the contributions to the standard uncertainty associated with the output estimate *y*, derived from the standard uncertainty of the input estimates x_i;

v_i - degree of freedom from the standard uncertainty contribution $u_i(y)$

The coverage factor *k* is chosen depending on the calculated value of V_{eff}. Table 2 shows the coverage multiplier *k* for the different effective degrees of freedom.

TABLE II. COVERAGE FACTOR *K* ON THE DIFFERENT EFFECTIVE DEGREES OF FREEDOM

Veff	*k*
1	13,97
2	4,53
3	3,31
4	2,87
5	2,65
6	2,52
7	2,43
8	2,37
10	2,28
20	2,13
50	2,05
∞	2,00

Table 3 presents the uncertainty budget, including quantities, evaluates, standard uncertainty of input evaluates, certainty factor and uncertainty contribution, and degrees of freedom used in the uncertainty analysis of alcohol concentration measurement.

TABLE III. UNCERTAINTY BUDGET

Quantity X_N	Estimate x_i	Probability distribution	Standard uncertainty $u(x_N)$	Sensitivity coefficients c_i	Contribution to the standard uncertainty, $u_i(y)$	Constituents of the combined standard uncertainty $u_i(y)$	Effective degrees of freedom, V_i
X_i	$\overline{x_i}$	normal	$u(x_i) = \sqrt{\frac{\sum_{j=1}^{n} (x_{i,j} - \overline{x_i})^2}{n(n-1)}}$	1	$C_i . u(x_i)$	$u_i(y)$	$v_1 = (n-1)$

X_r	0	rectangular	$u(x_r) = \frac{r}{2\sqrt{3}}$	-1	$C_i.u(x_r)$	$u(y_r)$	$v_2 = 50$
X_{CRM}	x_{CRM}	normal	$u(x_{CPM}) = \frac{U(x_{CRM})}{2}$	-1	$C_i.u(x_{CRM})$	$u(y_{CRM})$	$v_3 = \infty$
X_t	0	rectangular	$u(x_t) = \frac{C_{34+Ut/2} - C_{34-Ut/2}}{\sqrt{3}}$	-1	$C_i.u(x_t)$	$u(y_t)$	$v_4 = \infty$
Y	Y	Combined standard uncertainty, $u_c(y)$			$u_c(y) = \sqrt{\sum_{i-1}^{N} u_i^2\,(y)}$	$V_{eff} = \frac{u^4(y)}{\sqrt{\sum_{i-1}^{N} \frac{u_i^4(y)}{V_i}}}$	
		Expanded measurement uncertainty $U = 2u_c(y)$					

III. RESULTS OF MEASUREMENTS

This point presents the results of measurements made based on the developed mathematical model forming the uncertainty budget when measuring alcohol concentration with evidential breath analysers.

The measurement error was determined according to a test procedure [16], by performing a series of 10 consecutive measurements of alcohol concentration of 0.4 mg/L with Alcotest 7110 Evidential MK III evidential breath analysers at different temperatures. When determining the error, the uncertainty of the measurement was also evaluated. Tables 4 and 5 present the results of the calculated temperature uncertainty budget 32°C and 37°C.

A. Tehnical means used:

In fig. 2 shows the arrangement of standards and technical means

- Gas generator Dräger Alcocal 9000, - The function of the Dräger Alcocal 9000 is based on the enrichment of a carrier gas with ethanol by passing the gas through an ethanol-in-water solution at temperature 32°C и 37°C.
- CRM with value 1,029 g/l.
- Thermohygrometer for measuring environmental parameters.
- Temperature bath with simulator, type Simulator MARK IIA CE, holding temperature 34°C.
- Flow meter for controlling the flow rate of test gas.
- Thermometer, type DTM Spezial, to control the temperature of the CRM.
- Evidential breath analysers. type Alcotest 7110 Evidential MK III

B. Test conditions

The research used CRM and technical means traceable to international and national standards. Measurements are made under reference conditions to achieve the greatest degree of certainty.

Certified reference material is used to perform the prescribed tests to determine the error of evidential breath analysers. A gas saturated with water vapor with a known concentration of ethyl alcohol at a temperature of 34°C is created from an aqueous solution of CPM using a gas generator. This vapor-gas mixture is fed to the evidential breath analysers, simulating human breath profiles.

Fig. 1. Technical means used in examination and verification evidential breath analysers, type Alcotest 7110 Evident MK III

To obtain vapor-gas mixtures, the concentration of ethanol in the gas phase can be calculated with the Dubowski's formula [10]. Using Dubowski's formula represented by equation (19), the concentration of ethyl alcohol in the blood corresponding to the concentration of ethyl alcohol in an aqueous solution and the concentration of a vapor-air mixture (vapors of ethyl alcohol, water vapor and air) is calculated:

$$\beta_{(t)} = 0{,}04145 \times 10^{-3} \times \gamma_{(t)} \times e^{(0.06583 \times t)} \quad (19)$$

where:

β(t)- mass concentration of ethanol in the test gas at a given temperature *t* в mg/L;

$0{,}04145 \times 10^{-3}$ and 0,06583 conventional Dubowski coefficients

$\gamma_{(t)}$- mass concentration of ethanol in the aqueous solution at a given temperature in в mg/L;

t – temperature of solution and test gas in ˚C.

For t=34 ˚C the equation can be simplified to:

$$\beta_{(34)}=0{,}38866\times 10^{-3}\times\gamma_{(34)} \quad (20)$$

TABLE IV. THE CALCULATION UNCERTAINTY BUDGET WHEN MEASURING ALCOHOL CONCENTRATION AT A TEMPERATURE OF CRM 32°C

Quantity X_N	Evaluate of input quantity x_i	Standard uncertainty, $u(x_N)$	Probability distribution	Sensitivity coefficients, ci	Uncertainty contribution, u_i(y),
X_i	0.3986	0.00073	normal	1	0.0007
X_{CPM}	0.4	0.00041	rectangular	-1	-0.0004
X_r	0	0.00029	normal	1	0.0003
X_t	0	0.0017	rectangular	1	0.0017
k = 2 which, for a normal distribution, corresponds to a level of confidence of approximately 95%					
Expanded uncertainty U %=ku					0.0039

TABLE V. THE CALCULATION UNCERTAINTY BUDGET WHEN MEASURING ALCOHOL CONCENTRATION AT A TEMPERATURE OF CRM 37°C

Quantity X_N	Estimation of input quantity x_i	Standard uncertainty, $u(x_N)$	Probability distribution	Sensitivity coefficients, c_i	Uncertainty contribution, $u_i(y)$,
X_i	0.4031	0.0011	normal	1	0.0011
X_{CPM}	0.4	0.00041	rectangular	-1	-0.0004
X_r	0	0.00029	normal	1	0.0003
X_t	0	0.0017	rectangular	1	0.0017
k = 2 which, for a normal distribution, corresponds to a level of confidence of approximately 95%					
Expanded uncertainty U %=ku					0.0042

CONCLUSIONS

Sources affecting measurement uncertainty are identified.

Experimental validation of the mathematical model forming the uncertainty budget in the measurement of alcohol concentration with evidential breath analysers.

The analysis shows that the maximum established measurement error with the added contribution of measurement uncertainty is less than the maximum permissible error (MPE) or the inequality:

max. Δ ± U << MPE. (21)

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