Calibration of evidential breath analyzer for South African law enforcement

Gumani Mphaphuli

Mudalo Jozela, Napo G. Ntsasa, Tshepiso Mphamo and Portia Seemane

[1]National Metrology Institute of South Africa, Private Bag X34, Lynnwood Ridge,0040, South Africa

gmphaphuli@nmisa.org

Abstract

South Africa has one of the world's worst injury in road traffic statistics in the world, with 5% increase in death during the 2016/2017 holiday season. South Africans Against Drunk Driving (SADD) has reported a 20% increase in death in the past two years due to drunk driving [1]. An introduction of breathalyzers is one of the solutions in limiting and monitoring drunk and drive incidents. This instrument assists the law enforcement with the productiveness in roadside checkpoints which are extremely specific and definitive in computing alcohol content in the breath of a driver. With the legal limit for breath alcohol content being 0.24 milligrams per liter (mg/ℓ) for all licensed drivers and 0.1 mg/ℓ for professional drivers, the routine of breathalyzer checkpoint is important for public safety and determination of the soberness of licensed drivers in the country [2].

The paper will describe the calibration of evidential breath analyzers (EBA) by National Metrology Institute of South Africa (NMISA) to define the accuracy and quality of measurement uncertainty. The calibration of EBA is done by NMISA at concentration levels 0, 0.1 mg/ ℓ, 0.24 mg/ ℓ, and 0.8 mg/ ℓ as per the South African National Standard 1793:2013 (SANS). The calibration is aimed at verifying the accuracy, repeatability and temperature conversion of the EBA sensor. To demonstrate compliance of breathalyzers to these parameters, a method validation was conducted. The maximum permissible errors for the results were found to be below 0.01mg/l for concentrations below 0.2mg/ ℓ and less than 5% for concentrations above 0.4mg/ ℓ which is well below the SANS 1793:2013 specifications. The estimated standard deviation was found to be between 0 and 0.003 which is below the one third of maximum permissible errors of each individual concentration [3].

Keywords: calibration, evidential breath alcohol analyser, maximum permissible error

1. Introduction

Breath analyzers are devices that measure alcohol content absorbed from the mouth, throat, stomach and lungs through exhaled breath. The measurement system of the breathalyser consists of an infrared cell with an infrared source that absorbs at the 9,5 µm wavelength band (the most intense infrared absorption band in the infrared spectrum of ethanol). The infrared cell makes use of a multiple reflection path in a 100 mm cuvette to ensure sufficient sensitivity for ethanol in the concentration range 0 –3000 µg/ ℓ. The electrochemical cell measures the ethanol simultaneously with the infrared cell [4].

With high drunk driving levels reported in South Africa, precise calibration of breathalysers essential. NMISA gas analysis laboratory has been responsible for dry gas calibration of the EBA as part of its mandate to establish national measurement standards for gaseous substance to the South African industry since 1997. This is after the International Organization of Legal Metrology (OIML) published a standard titled OIML R 126" Evidential breath analyzers" [5]. The specifications were developed by a technical committees and suitable stakeholders.

With the continuous advancement of scientific knowledge, a new Dräger Alcotest 9510 model with dual sensor technology (infrared and electrochemical cell) and intuitive color touch screen was introduced to the market uses wet gas calibration method [6]. This method allows the opportunity to mimic the human body temperature and location of the lungs to provide a more accurate calibration output. As a mandate, NMISA has developed a new wet bath method for Dräger Alcotest 9510 model, as the law enforcement breath analyzers need to be precisely maintained and re-calibrated frequently to ensure accuracy. Precision, accuracy, and maximum permissible errors are the major metrological necessities for the EBA's calibration.

The Dräger Alcotest 9510 ZA is a device capable of satisfying the strict requirements of SANS 1793:2013 for evidential breath alcohol analysis specifically for South Africa. The method used to calibrate the evidential breathalyser involves bubbling dry gas through certified aqueous solutions of ethanol that is traceable to the International System of Units (SI). The air bubbled through the solution producing the known concentration of wet gas that the EBA identifies and gives a read out of the observed concentration through the sensors.

2. Methodology

2.1. Research purpose

The purpose of the research is to calibrate the EBA to define the accuracy and quality of measurement uncertainty by testing the instrument's conversion of alcohol mass concentration at breath temperature to a mass concentration at 34.°C for concentrations in the range 0.0 mg/ ℓ to 0.8 mg/ ℓ.

2.2. Research approach

2.2.1. Calibration of certified reference standards

Certified reference materials of ethanol solution were prepared gravimetrically at 20 ℃ ± 2 ℃ and certified at the NMISA organic laboratory. The certified reference materials of aqueous ethanol of known composition and uncertainty are directly traceable to the SI unit of amount of substance. The mass concentration of ethanol in air was calculated using Dubowski's equation at 34˚C.

$$C_{gas} = C_{solution} \cdot K_0 \cdot e^{A \cdot T} \qquad (1)$$

Where:
C_{gas} is the resulting ethanol concentration of the gas mixture in mg/ ℓ
$C_{solution}$ is the ethanol solution of the water-ethanol solution in g/ ℓ
$K_0 = 4.145\times10^{-2}$ Henry coefficient for ethanol

$A = 0.06583\ \frac{1}{°C}$ temperature dependency constant

T is the temperature of the gas mixture in ℃

2.2.2. Calibration of evidential breath alcohol analyzer

The Henry's law which states that 'at constant temperature, the amount of a given type and volume of liquid is directly proportional to the partial pressure of that gas in equilibrium with that liquid' command the relation between the breath alcohol composition and the blood alcohol content [8]. The calibration of the EBA are carried out according to the manufacturer's specifications and the guidance provided in the SANS 1793:2013 specifications.

The breath alcohol analysers are calibrated making use of certified aqueous ethanol solution at concentartions of 0.0 mg/ ℓ, 0.1 mg/ ℓ, 0.24 mg/ ℓ and 0.8 mg/ ℓ systematically. All concentrations are prepared in air at 34℃ .At each concentration level, ten measurements are perfomed to determine the precision and accuracy of the instruement.

Then the accuracy of the alcohol mass concentration conversion test is performed using 0.24 mg/ ℓ at 32 ℃, 34 ℃ and 37 ℃. This is performed to ensure the instruments performance at different temperature of the subjects. At each temperature, ten measurements are perfomed to determine the precision and accuracy of the instruement's temperature sensor [3].

It is important to note that the EC and IR sensor responses shoulod be within 5% of each other as per manufacturer specifications.

3. Results and Discussion

For this study, a quantitative approach was followed. The main characteristic of interest is to disclose instrument's range of performance and the perspicacity that drive it with reference to calibration. Thus, making the results more descriptive than predictive [6]. The research held with the calibration was adopted from the OIML into the SANS 1793:2013. The confirmation was carried out by a collection of experimental data that fulfil the SANS 1793:2013 analytical requirements for the calibration. A method validation was conducted to examine fit for purpose calibration method.

3.1. Repeatability

Repeatability of a measurement method is defined as the closeness of the agreement between the results of successive measurements of the same measurand carried out under the same conditions of measurement [7]. This requires the measurement to be performed several times by one technique. The repeatability study was done in one day across four different concentrations under similar conditions as shown in figure 1. The results in table 1 show standard deviation of all mass concentration as less than one third of the maximum permissible error which satisfies the SANS 1793:2013 requirements, indicating repeatability of the method across the concentration range 0.00 mg/ ℓ to 0.799 mg/ ℓ.

Table 1: Repeatability tests performed on one day on Alcotest 9510 ZA

Certified concentration (mg/ l)	**Observed concentration average (mg/ l)**		**Standard deviation**		**SANS standard deviation Specifications**
	IR	**EC**	**IR**	**EC**	
0.000	0.000	0.000	0.000	0.000	N/A
0.100	0.097	0.099	0.0007	0.00110	≤ 0.0067
0.242	0.243	0.240	0.0008	0.0015	≤ 0.0067
0.799	0.828	0.792	0.0036	0.0032	≤ 0.014

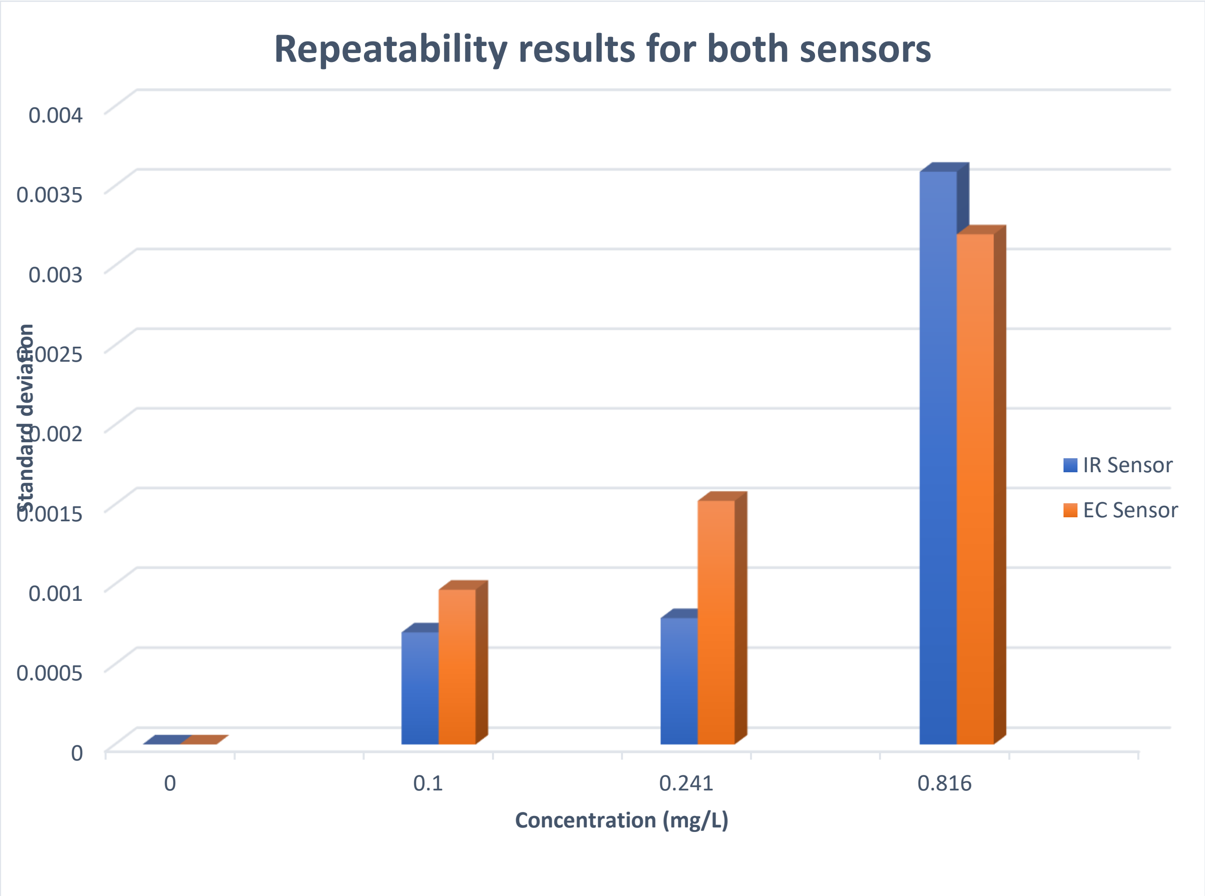

Figure 1. Repeatability data for both sensors.

3.2. Accuracy

With the legal limit for drivers being 0.24 mg/ ℓ and that of professional drivers being 0.1 mg/L, proving accuracy is of fundamental importance.

To determine accuracy, the average of 10 replicates of each concentration was compared to the SANS 1793:2013 Section 5.2.1 specifications. The results in table 2 show that the method is accurate for the calibration concentration range.

Table 2. Comparison of concentration averages and SANS specifications.

Concentration (mg/L)	**Average from repeatability results (mg/L)**		**SANS Specifications (mg/L)**
	IR Sensor	**EC Sensor**	
0.100	0.097	0.099	0.080 to 0.120
0.242	0.243	0.240	0.220 to 0.262
0.799	0.828	0.792	0.759 to 0.839

3.3.Recovery

The bias is defined as the difference between the expectation of the test results and an accepted reference value.

The bias of the method was determined by calculating the percentage recovery from the accuracy results per the equation 2 below:

$$\%\,Recovery = \frac{Average\,value}{Certified\,value} \times 100\% \qquad (2)$$

The recovery results of each concentration are shown in table 3. IR and EC sensor show positive bias results with both sensors results within the accuracy specification.

Table 3. Recovery of the IR and EC sensor

Concentration (mg/ℓ)	**IR Recovery (%)**	**EC Recovery (%)**
0.100	96.60	99.40
0.242	100.50	99.21
0.799	103.63	99.12

Linearity

Linearity is an important validation parameter for comparative methods where measurements are made over a range of concentrations. A linearity study verifies that the standards are in a concentration range where the analyte response is linearly proportional to concentration. The number of standards used is important because this affects the precision of the method and the blank should be included.

For the linearity study, Table 4 shows regression results obtained for concentrations 0.0 mg/ℓ, 0.100 mg/ ℓ, 0.242 mg/ ℓ and 0.8799 mg/ ℓ of ethanol solution. Linearity is expressed by the correlation coefficient (r^2). The data is plotted on graphs (Figure 4 and 5) for visual examination of linearity.

From table 4 below, R^2 ranges between 0.9999 and 1 (refer to graphs below), which is indicative of good linearity on both IR sensor and EC sensor.

Table 4. Linearity of IR and EC sensors

Sensor	IR	EC
Multiple R	0.999943632	0.999999929
r Square	0.999887268	0.999999857
Adjusted R Square	0.999830902	0.999999786
Standard Error	0.004637175	0.000164998

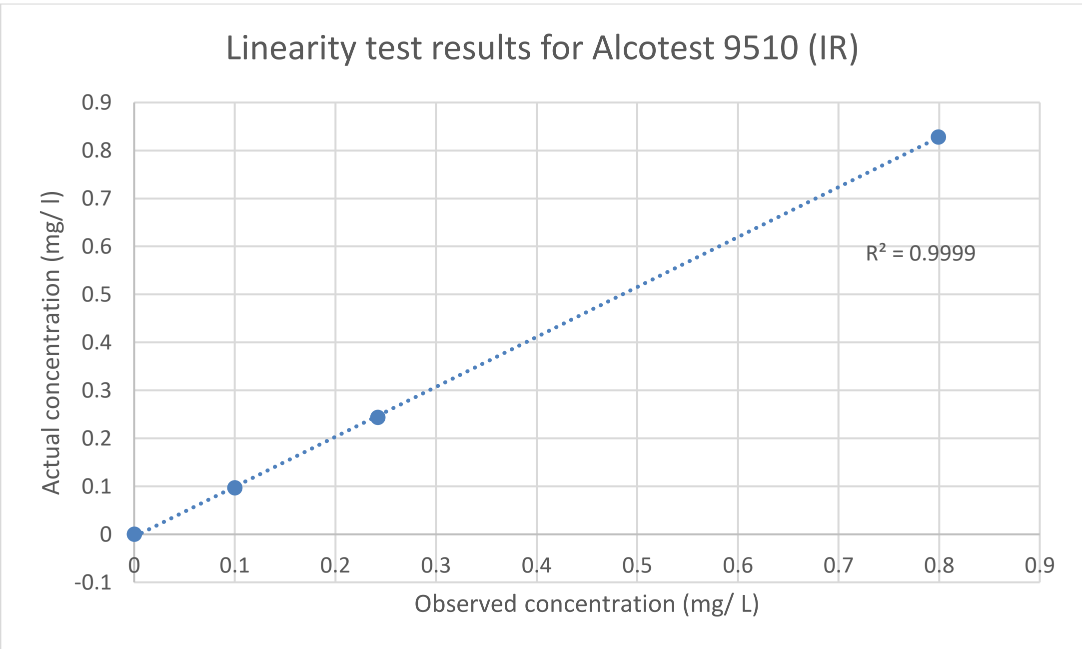

Figure 4. Linearity test for Alcotest 9510 (IR)

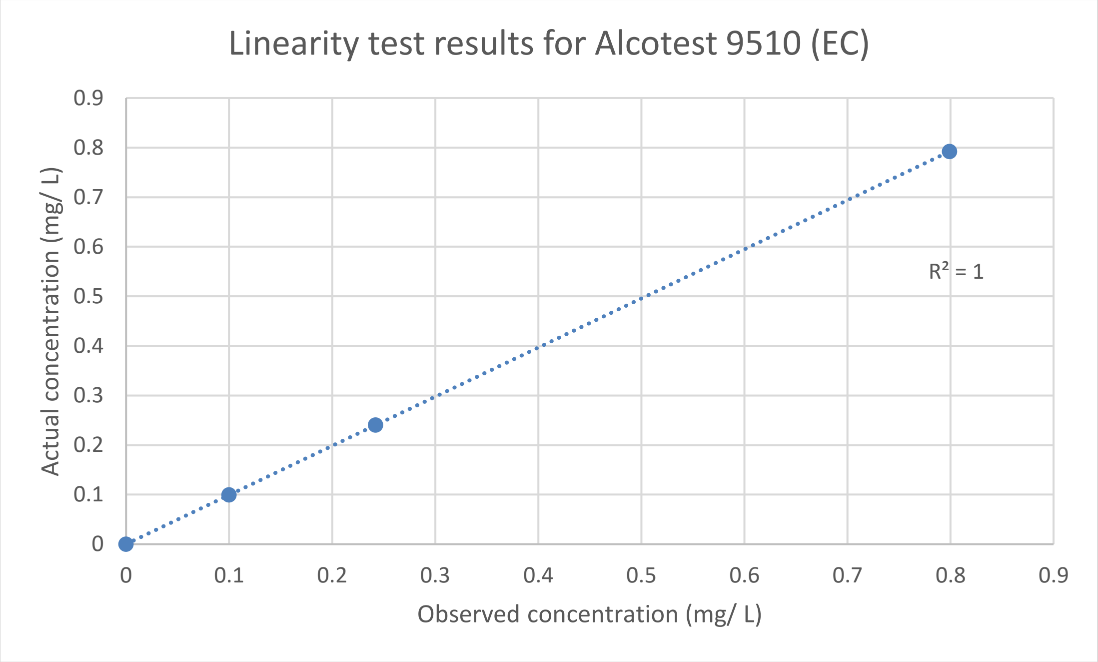

Figure 5. Linearity test for Alcotest 9510 (EC)

3.4. Temperature Conversion

The evidential breath analyser is provided with a temperature sensor that has the capacity to measure temperature of the test subject breath sample and convert it to breathe alcohol concentration at a temperature of 34°C using the Dubowski equation (1).

To ensure accurate function of temperature sensor, 0.241 mg/ℓ of ethanol in water solution was tested for the conversion of alcohol mass concentration at breath temperature to mass concentration at 32 °C, 34 °C and 37 °C by performing 10 measurements at each temperature. The results in table 5 show that the results fall within the SANS specifications.

Table 5. Temperature conversion data for 0.241mg/l at 32, 34 and 37°C.

Temperature (°C)	**32**		**34**		**37**	
Concentration (mg/ l)	**0.212**		**0.242**		**0.295**	
	IR	**EC**	**IR**	**EC**	**IR**	**EC**
Average (mg/ l)	0.212	0.210	0.241	0.239	0.294	0.291
Std deviation	0.002	0.002	0.001	0.002	0.001	0.001
SANS Specifications (mg/l)	0.192 to 0.232		0.222 to 0.262		0.275 to 0.315	

4. Conclusion

With South Africa having the worst injury in road traffic statistics in the world, traceability of measurement for EBA is of high importance. These measurements impact the law enforcement directly and thus the NMISA's certificate of calibration is accepted in South African courts as *prima facie* evidence. Wet gas calibration has proved to be more reliable with the impersonation of human body and its temperature.

5. References

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