

Vapor-Alcohol Control Tests with Compressed Ethanol-Gas Mixtures: Scientific Basis and Actual Performance

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Abstract

Commercial compressed vapor-alcohol mixtures ("dry gas") were evaluated to ascertain their suitability for control tests in breath-alcohol analysis. Dry gas control tests were conducted at nominal vapor-alcohol concentrations (VACs) of 0.045, 0.085, and 0.105 g/210 L ($n = 50$ at each VAC) with Alcotest 7110 MK III and Intoxilyzer 1400 evidential breath-alcohol testers. The measurement results were analyzed by standard statistical methods, and their correlation with certified dry gas VAC target values was examined. Also measured and examined statistically were the VACs of National Institute of Standards and Technology-traceable Research Gas Mixtures (dry gas) ethanol standards at 97.8 and 198 ppm ($n = 30-50$ at each VAC). With the Alcotest 7110 MK III programmed to report VACs normalized to standard atmospheric pressure at 760 torr and the Intoxilyzer 1400 programmed to report VACs at ambient atmospheric pressure, the predicted effects of ambient atmospheric pressure were confirmed experimentally. We developed and validated the following conversion factor for VAC units at 34°C and 760 torr: $\text{ppm}/2605 = \text{g}/210 \text{ L}$ and $\text{g}/210 \text{ L} \times 2605 = \text{ppm}$. We found that the dry gas vapor-alcohol control samples conformed to established formal specifications and concluded that they compared favorably with simulator effluents for control tests of breath-alcohol analyzers which are capable of adjusting VAC results for ambient atmospheric pressure.

Introduction

Compressed mixtures of ethanol with an inert gas such as nitrogen ("dry gas") have been commercially available for approximately 25 years for use in calibrating breath-alcohol¹ analyzers and in conducting control tests of such devices. They have been in even longer use in our laboratory as vapor-alcohol standards custom-prepared to our specifications. Recently, greatly increased use of such dry gas mixtures has resulted from the large-scale breath-alcohol testing in the transportation workplace, which has begun pursuant to the mandate of

the federal Omnibus Transportation Employee Testing Act of 1991 (Public Law 102-143). The pertinent federal (Department of Transportation [DOT]) regulations require compliance with quality assurance plans (QAPs) established by the manufacturers of the breath-alcohol analyzers used in such regulated testing. Several manufacturers' QAPs provide for control tests ("external calibration checks") with dry gas as an alternative to use of alcoholic breath simulators. We have, therefore, experimentally evaluated such commercially available dry gas mixtures, and we present our findings and conclusions together with a brief consideration of the scientific basis for alcohol measurements, under ambient conditions, of vapor-alcohol samples derived from compressed ethanol-gas mixtures.

Theoretical Basis for Use of Compressed Vapor-Alcohol Mixtures (Dry Gas)

Nomenclature and units

Some consideration of nomenclature and units is pertinent to what follows. This study primarily concerned gases and vapors and mixtures thereof. Reduced to essentials, a gas is a fluid possessing perfect molecular mobility and the property of infinite expansion (as opposed to the other states of matter—solid and liquid), that is, tending to occupy the total volume of any container into which it is introduced. Gases follow, with considerable fidelity, physical laws relating their conditions of pressure, volume, and temperature; they mix freely with other gases and vapors with which they do not react. A vapor², in the present context, is the gaseous state of a substance that generally exists as a liquid or solid at normal ambient temperature and pressure. Typical examples of vapor are water vapor and vaporized ethanol. The effluent or output of an alcoholic breath simulator at 34°C consists principally of two vapors, ethanol and water, uniformly dispersed in a mixture of gases (air). Simulator effluent is, therefore, properly characterized as a vapor-gas mixture. A dispersion of alcohol in nitrogen or in

¹ The unmodified term alcohol in this article refers to ethanol.

² More formally, vapor is a gaseous substance below its critical temperature that can, therefore, be liquefied by pressure alone.

other inert gases, whether in compressed form³ or reexpanded to atmospheric pressure, is also a vapor-gas mixture. It is, therefore, correct and convenient to refer to the vapor-alcohol concentration (VAC) in either kind of mixture. Compressed alcohol-gas mixtures must be free of water vapor to retain the basic gas property of microhomogeneity. Hence, the convention is to refer to such alcohol-in-gas mixtures as "dry gas". In contrast, simulator effluent is essentially saturated with water vapor and is thus, by convention, often referred to as "wet gas". That nomenclature is adopted here: Dry gas means a compressed or decompressed alcohol-gas mixture, and wet gas means simulator effluent.

VACs are expressed in different units for various purposes and in different jurisdictions. A common European VAC unit is micrograms/liter. In the United States, VAC is universally expressed in units of grams per 210 L (g/210 L). In the compressed gas industry and for certain other purposes such as in stating workplace hazard exposure limits, concentrations of gases and vapors and their mixtures are generally stated in units of parts per million, meaning parts by volume of the target substance per million parts by volume of the total mixture. Because the unit notation *parts per million* is a simple proportion, $1/10^6$, the parts-per-million value is independent of pressure or temperature in compressed or decompressed gases or vapors, whereas restatement in mass-per-unit-volume concentration units requires a conversion factor, as will be described.

Atmospheric pressure is considered to be the pressure exerted by the atmosphere on a surface at any given point. The common and traditional scientific notation for atmospheric pressure has been in units of millimeters of mercury (mm Hg); the numerically equal "torr" notation is now commonly used. The traditional standard conditions of temperature and pressure (STP) for most scientific purposes are 273.15 K (equal to 0°C) and 760 torr. Atmospheric pressure is measured by barometry (1), traditionally with mercury barometers for scientific purposes and official weather forecasting; currently, it is also measured by digital barometry with piezoelectric pressure sensors or other solid-state pressure transducers. By international action in 1954, 1 standard atmosphere (atm) is defined as a pressure of 1013.250 millibars (mb) (1). One torr, as a unit of pressure, equals $1/760$ atm and is therefore equal to $1013.250/760$ (1.333 mb) and is numerically equal to 1 mm Hg. Atmospheric pressure is indicated by the Alcotest 7110 MK III in hectoPascals (hPa) and by the Intoxilyzer 1400 in mb; 1 standard atm approximates 1013.3 hPa or 1013.3 mb.

Properties of gases and gas laws

All gases share certain properties and characteristics. In the present context, some simplifying assumptions are made. Gases differ importantly from liquids and solids in that the volume of a gas sample depends strikingly on the temperature of the gas and on the applied pressure. For example, the volume of a sample of air is reduced by one-half when the pressure is in-

creased from 1 to 2 atm, and it increases by 35.6% when its temperature is raised from 0 to 100°C (2). Accordingly, the actual measurement of the volumes of gases, vapors, and gas-vapor mixtures must be either corrected to standard conditions (STP, 0°C, and 760 torr) or given for other stated conditions of temperature and pressure.

Several key physicochemical relationships apply to gases and are usually expressed in the form of natural laws (3). Boyle's law states that the volume of a given mass of gas varies inversely as the pressure, at constant temperature, or $PV = \text{constant}$. The law of Charles and Gay-Lussac states that the volume of a given mass of gas varies directly as the absolute temperature (in Kelvin), at constant pressure, or $V/T = \text{constant}$. Avogadro's law, $V \propto n$, can be stated as follows: Equal numbers of molecules are contained in equal volumes of all dilute gases under the same conditions. The molar volume of an ideal gas is the volume occupied by 1 mol of gas at STP, 22.414 L/mol (4). Dalton's law of partial pressures states that in a gas mixture the molecules of each component gas exert the same pressure as they would if present alone at the same temperature and that the total pressure is the sum of the partial pressures exerted by the different, nonreacting gases in the mixture (5), $P_{\text{total}} = P_1 + P_2 + P_3 + \dots$

Boyle's law, the law of Charles and Gay-Lussac, and Avogadro's law can be combined into a single ideal gas equation, also called the General Gas Law: $PV = nRT$, where n is the number of moles of gas in the sample, and R is the gas constant the numerical value of which depends on the units used for pressure, volume, and temperature (6). With dry gas mixtures, a Dalton's law correction for the partial pressure of water vapor is not required. Application of the foregoing physical laws and principles allows adjustments for variations in the conditions of gases and vapors and permits interchange among units of concentration.

Conversion factor for vapor-ethanol concentrations

As previously noted, the alcohol content of compressed dry gas materials, dry gas cylinder-VAC labeling, and certificates of analysis of dry gas VACs are commonly stated in parts-per-million units, whereas breath-alcohol analyzers are calibrated and report VAC in g/210 L concentration units. To relate these two units of VAC, a conversion factor is required.

It follows from the foregoing considerations, and especially from the General Gas Law and Dalton's law of partial pressures, that the following general conversion formulas apply:

For any compound at 0°C and 760 torr

$$\text{ppm} \times \frac{g \text{ mol wt}}{1000 \times 22.414} = \text{mg/L} \quad \text{Eq 1}$$

and

$$\text{mg/L} \times \frac{1000 \times 22.414}{g \text{ mol wt}} = \text{ppm} \quad \text{Eq 2}$$

where $g \text{ mol wt}$ is the gram molecular weight. For any compound at 34°C and 760 torr

³By convention, compressed gas is any gaseous material or mixture that, in a container, has either an absolute pressure exceeding 40 psi at 70°F or an absolute pressure exceeding 104 psi at 130°F, regardless of the pressure at 70°F.

$$\text{ppm} \times \frac{g \text{ mol wt}}{1000 \times 25.204} = \text{mg/L} \quad \text{Eq 3}$$

and

$$\text{mg/L} \times \frac{1000 \times 25.204}{g \text{ mol wt}} = \text{ppm} \quad \text{Eq 4}$$

where the molar volume at 34°C and 760 torr is equal to

$$22.414 \times \frac{(273.15 + 34)}{273.15} = 25.204 \text{ L/mol} \quad \text{Eq 5}$$

For ethanol (g mol wt, 46.07) at 34°C and 760 torr

$$\text{ppm} \times \frac{46.07}{1000 \times 25.204} = \text{mg/L} \quad \text{Eq 6}$$

and

$$\text{mg/L} \times \frac{1000 \times 25.204}{46.07} = \text{ppm} \quad \text{Eq 7}$$

whence

$$\text{ppm} \times 0.0003839 = g/210 \text{ L} \quad \text{Eq 8}$$

and

$$\frac{\text{ppm}}{2605} = g/210 \text{ L} \quad \text{Eq 9}$$

and

$$g/210 \text{ L} \times 2605 = \text{ppm} \quad \text{Eq 10}$$

These ppm \rightarrow g/210 L and g/210 L \rightarrow ppm conversion factors reflect the 34°C convention for use of dry gas as a vapor-alcohol calibrator or control material and were used by us in the experimental studies reported here.

Experimental

Laboratory procedures and testing were carried out in accordance with all applicable safety considerations and in compliance with recognized standards of good laboratory practice.

Vapor-alcohol measurement. The alcohol concentration of dry gas samples was measured with an Intoxilyzer 1400 (CMI, Inc., Owensboro, KY) by infrared (IR) spectrometry at 3.39/3.48/3.80 μm and with an Alcotest 7110 MK III (National Draeger, Inc., Durango, CO) by IR spectrometry at 9.5 μm and by electrochemical oxidation. Both instruments are micro-processor-controlled evidential breath testers and were used with factory calibrations of vapor alcohol in g/210 L. VAC measurements included the following automated, software-controlled steps: air blank, VAC₁, air blank, VAC₂, air blank, VAC₃, air blank, and so on. Results of VAC measurements of air blanks, dry gas, and wet gas controls (simulator-generated vapor-alcohol samples) were displayed and printed contemporaneously in g/210 L to three decimal places. The Alcotest 7110 MK III was programmed to report dry gas VACs normalized to standard atmospheric pressure (760 torr); the Intoxilyzer 1400 was programmed to report dry gas VACs at ambient atmospheric pressure. Before each measurement of alcohol in individual or replicate dry gas samples, proper functioning of the breath tester was established by completion of the programmed test-initiation sequence; simulator-effluent control tests at 0.05 and 0.10 g/210 L were performed before and after dry gas measurements to establish correct calibration of the analyzers within acceptable limits for this project (± 0.005 g/210 L). Both dry gas samples and wet gas controls were introduced into the control-sample port of the Intoxilyzer 1400. Dry gas samples were introduced into the gas port of the Alcotest 7110 MK III, whereas wet gas controls were introduced through the breath intake tube. Typical instrument parameters of vapor-alcohol measurements of dry gas and wet gas are shown for both analyzers in Table I. Vapor-alcohol measurements were carried out in the laboratory at an altitude of 1225 ft (373.4 m) and at prevailing ambient atmospheric pressure and temperature (e.g., 731 torr and 23°C).

Vapor-alcohol control samples. Vapor-alcohol samples (wet gas) for use as controls were generated using production units of Guth model 34C and model 10-4 Alcoholic Breath Simulators (Guth Laboratories, Harrisburg, PA), operated at 34°C, with verified factory temperature adjustment. Simulator effluent (wet gas) was produced by equilibration of the aqueous alcohol solution with flowing air. Room air was drawn into the simulator, and effluent was aspirated from the simulator by the analyzer's internal pump with the Intoxilyzer 1400. Simulator effluent was produced with flowing air from a compressed breathing air cylinder with the Alcotest 7110 MK III.

Simulator solutions. Simulators were filled with 0.5 L of aqueous alcohol solutions prepared and verified to yield VACs

Table I. Typical Instrument Parameters for Vapor-Alcohol Measurements with Alcotest 7110 MK III and Intoxilyzer 1400 Evidential Breath Testers

Instrument	Test	Inlet pressure at analyzer	Flow time (s)	Mean volume (L)	Mean flow rate (mL/s)
Alcotest 7110*	Simulator (wet gas) control	5 in. H ₂ O	11	1.9	173
	Dry gas control	8 psi	7	1.0	143
Intoxilyzer 1400†	Simulator (wet gas) control	—‡	10	0.4	40
	Dry gas control	15 psi	6	0.24	40

* Wet gas samples were introduced into the Alcotest 7110 through the breath tube and dry gas samples into the gas port.

† Wet gas and dry gas samples were introduced into the Intoxilyzer 1400 through the external control sample port.

‡ Simulator effluent (wet gas) is aspirated by the instrument.

(wet gas) of 0.00, 0.05, and 0.10 g/210 L at 34°C as previously described (7). Alcohol in simulator solutions was analyzed by automated gas chromatographic headspace analysis with a model F-45 vapor space chromatograph (Perkin-Elmer, Norwalk, CT), as previously described (8).

Vapor-alcohol dry gas control samples. The dry gas vapor-alcohol mixtures were commercially available, compressed ethanol-in-nitrogen mixtures, supplied as Ethanol Breath Standard (EBS™) in Scotty V cylinders, containing 105 L of dry gas at 1100 psig and 70°F when full (Scott Specialty Gases, Plumsteadville, PA). Gas manufacturer-furnished model 27 single-stage preset gas pressure regulators, model 14 two-stage high-purity series adjustable-flow pressure regulators, and part no. 120B127 adjustable-pressure regulators (Scott Specialty Gases) were used to reduce the dry gas from cylinder to delivery pressures. The dry gas EBS mixtures had lot-certified VAC values as follows: 118 ppm (equal to 0.045 g/210 L) \pm 2%, 221 ppm (equal to 0.085 g/210 L) \pm 2%, and 273 ppm (equal to 0.105 g/210 L) \pm 2%. The stated VACs certified by the manufacturer correspond at 760 torr atmospheric pressure and 34°C to the stated parts-per-million values, in accordance with the conversion factor ppm/2605 = VAC (in g/210 L).

Vapor-alcohol dry gas reference samples. These materials were dry gas ethanol standards and were prepared as ethanol-in-nitrogen compressed gas mixtures and supplied as Acublend Master Gas (Scott Specialty Gases). The AL aluminum cylinders contained about 3700 L of dry gas at 2000 psig and 70°F when full. These dry gas mixtures had certified ethanol concentrations of 97.8 ppm \pm 1% and 198 ppm \pm 1% traceable to National Institute of Standards and Technology (NIST) Research Gas Mixtures (RGM) dry gas ethanol standards, which corresponded, respectively, to 0.0375 g/210 L \pm 1% and 0.0760 g/210 L \pm 1% at 760 torr atmospheric pressure and 34°C. A standard two-stage high-purity adjustable gas pressure regulator with a needle flow valve and a toggle on-off valve was used to control delivery pressures and flow rates.

Temperature, volume, pressure, and atmospheric pressure measurements. Temperatures, simulator effluent and dry gas volumes, and simulator outflow and dry gas regulator exit pressures were measured as previously described (7). Ambient

atmospheric pressure and laboratory room temperature were measured, at the time of each individual or set of dry gas vapor-alcohol analyses, with a model 7400 digital barometer-thermometer (Davis Instruments, Hayward, CA), which was calibrated and rechecked at least daily against known reference sources. For room temperature, this was a reference grade mercury-in-glass thermometer with readings traceable to a NIST standard reference material 934 thermometer (NIST, Gaithersburg, MD). For barometric pressure, the reference source was a model 453 National Weather Service-type Fortin mercurial barometer (Princo Instruments, Southampton, PA) with calibration traceable to and verified at least once daily against National Oceanic and Atmospheric Administration National Weather Service hourly barometric pressure measurements at the Oklahoma City Airport weather station. Appropriate mercurial barometric reading corrections were applied for barometer temperature, gravity at our 35°28' latitude, and the sea level differential for the laboratory at 1225 ft (373.4 m), as required (1). The calculated VAC of dry gas at ambient atmospheric pressure in the laboratory was also verified against an Everest model APC II barometric pressure-sensing automatic pressure compensator (Plus 4 Engineering, Inc., Minturn, CO) calibrated for 0.040 and 0.100 g/210 L nominal VACs at 760 torr. Unless otherwise stated, we used the 34°C convention in converting parts per million to g/210 L VAC.

Statistical analysis. Statistical examinations and data analysis were carried out by standard statistical methods (9,10) using STATGRAPHICS® Plus, version 6.0 (1992) software (Manugistics, Inc., Rockville, MD) with a microcomputer for both descriptive statistics and significance testing.

Results

Calibration checks of breath-alcohol analyzers

Before alcohol measurements on dry gas samples, the

Table II. Control of Alcotest 7110 MK III and Intoxilyzer 1400 Evidential Breath Testers with Simulator-Generated Vapor-Alcohol Samples (Wet Gas)

Analyzer	Number of tests	Vapor-alcohol concentration (VAC) (g/210 L)	
		Nominal VAC	Measured VAC (Mean \pm SD*)
Alcotest 7110†	25	0	0 \pm 0
	25	0.05	0.049 \pm 0.0007
	25	0.10	0.100 \pm 0.0001
Intoxilyzer 1400	25	0	0 \pm 0
	25	0.05	0.050 \pm 0.0002
	25	0.10	0.099 \pm 0.0005

* SD = Standard deviation.

† Infrared analysis channel of the Alcotest 7110 was used for these measurements.

Table III. Calibration Checks of Alcotest 7110 MK III and Intoxilyzer 1400 Evidential Breath Testers with NIST®-Traceable RGM† Ethanol Standards (Dry Gas)

Analyzer	Number of tests	RGM Vapor-alcohol concentration (VAC)		
		ppm	g/210 L	
		Certified value	Nominal VAC [‡] span	Measured VAC [‡] (mean \pm SD [§])
Alcotest 7110	40	97.8 \pm 1%	0.037–0.038	0.037 \pm 0.0006
	30	198 \pm 1%	0.075–0.076	0.075 \pm 0.0005
Intoxilyzer 1400	50	97.8 \pm 1%	0.035–0.036	0.036 \pm 0.0003
	50	198 \pm 1%	0.072–0.073	0.072 \pm 0.0002

* NIST = National Institute of Standards and Technology.

† RGM = Research gas mixtures.

‡ Nominal and measured VACs are shown at a standard atmospheric pressure of 760 torr for the Alcotest 7110 and at an ambient atmospheric pressure of 731 torr for the Intoxilyzer 1400.

§ SD = Standard deviation.

|| The infrared analysis channel of the Alcotest 7110 was used for these measurements.

validity of the calibrations of both evidential breath-alcohol testers in the pertinent VAC range was confirmed with wet gas simulator-generated vapor-alcohol samples at 0.05 and 0.10 g/210 L nominal VACs; these results are shown in Table II. Applicability of these analyzer calibrations to measurement of alcohol in dry gas samples was independently confirmed by testing dry gas NIST RGM-traceable ethanol standards at $97.8 \pm 1\%$ and $198 \pm 1\%$ ppm. The results are summarized in Table III. The corresponding VAC result spans were 0.036–0.038 and 0.074–0.076 g/210 L for the Alcotest 7110 MK III and 0.036–0.037 and 0.072–0.073 g/210 L for the Intoxilyzer 1400. One-sample statistical analysis of variance of these dry gas RGM ethanol standard results showed that the certified nominal VACs fell within the 95% confidence intervals for these dry gas tests with both analyzers, thus excluding systematic analytical bias (11).

Accuracy and precision of alcohol tests on dry gas samples

The principal experimental data obtained in this study for within-run tests are summarized in Tables IV and V for each of the three dry gas controls, along with the descriptive statistics of the results. Best-fit linear regression analysis of the mean values of the dry gas control results upon their respective certified nominal VAC values yielded the following two equations:

$$y = 0.993x + 0.0002; r = 0.999 \quad \text{Eq 11}$$

for the Alcotest 7110 MK III (IR Channel) and

$$y = 1.000x + 0; r = 1.00 \quad \text{Eq 12}$$

for the Intoxilyzer 1400, where x is equal to the certified nominal mean control VAC (g/210 L), y is equal to the dry gas control test result (g/210 L), and r is the Pearson correlation coefficient for the regression.

The correlation of nominal VACs of the dry gas controls with the mean measured VACs within-run as an indicator of accuracy of the measurements is shown in Figure 1 for the Alcotest 7110 MK III and in Figure 2 for the Intoxilyzer 1400. Each graph also includes measurement means for the dry gas NIST-traceable RGM 97.8 and 198 ppm ethanol standards as listed in Table III; however, those RGM dry gas results were not included in the regression analysis of the dry gas control test results.

The accuracy of replicate within-run alcohol measurements of dry gas, as well as their precision or within-run repeatability, is shown graphically in Figures 3 and 4 for the Alcotest 7110 MK III (IR channel) and Intoxilyzer 1400, respectively. The underlying experimental data are those summarized in Tables

IV and V. The dry gases analyzed were the same for both analyzers. However, as already noted, the Alcotest 7110 MK III was programmed to report VAC results normalized to 760 torr, whereas the Intoxilyzer 1400 was programmed to report VAC results at ambient atmospheric pressure, typically 722–731 torr for this study.

Alcohol tests on dry gas from different cylinders and between-runs

Agreement between vapor analysis results on dry gas controls from different Scotty V cylinders bearing the same lot number and with the same certified VAC (0.045 g/210 L $\pm 2\%$ at 760 torr) was tested repeatedly. For example, sets of 37 and 20 vapor alcohol measurements were performed consecutively on the same day on two Scotty V cylinders with a nominal certified label VAC value of 0.045 g/210 L $\pm 2\%$ at an ambient atmospheric pressure of 731 torr using the Alcotest 7110 MK III; typical results are shown in Table VI. Other split-cylinder same-lot same-day trials yielded comparably convergent results with the Intoxilyzer 1400.

Between-run variability of dry gas control measurements was tested during a period of 2 months; the results shown in Table VII are typical. These three sets of measurements with the Intoxilyzer 1400 reflect separate runs on dry gas controls from three different Scotty V cylinders bearing the same

Table IV. Within-Run Vapor-Alcohol Measurements of Dry Gas with the Alcotest 7110 MK III

Number of tests	Detector	Nominal VAC* (g/210 L)	Measured vapor-alcohol concentration (VAC) (g/210 L) [†]				
			Mean	SD [‡]	median	mode	span
50	IR [§]	0.044–0.046	0.045	0.0005	0.046	0.046	0.045–0.046
	EC		0.044	0.0009	0.044	0.044	0.042–0.046
50	IR	0.083–0.086	0.085	0.0005	0.085	0.085	0.085–0.087
	EC		0.084	0.0007	0.084	0.084	0.083–0.086
50	IR	0.102–0.107	0.104	0.0006	0.104	0.104	0.104–0.106
	EC		0.103	0.0006	0.103	0.103	0.102–0.105

* The nominal VAC span at a standard atmospheric pressure of 760 torr for the dry gas lot-certified VAC value $\pm 2\%$.

[†] Results were normalized by the instrument to a standard atmospheric pressure of 760 torr.

[‡] SD = Standard deviation.

[§] IR = Infrared.

^{||} EC = Electrochemical.

Table V. Within-Run Vapor-Alcohol Measurements of Dry Gas with the Intoxilyzer 1400

Number of tests	Nominal VAC* (g/210 L)	Measured vapor-alcohol concentration (VAC) (g/210 L) [†]				
		mean	SD [‡]	median	mode	span
50	0.042–0.044	0.043	0.0003	0.043	0.043	0.042–0.043
50	0.080–0.083	0.081	0	0.081	0.081	0.081
50	0.099–0.103	0.101	0.0004	0.101	0.101	0.100–0.101

* The nominal VAC span at an ambient atmospheric pressure of 731 torr for the dry gas lot-certified VAC value $\pm 2\%$.

[†] Results were reported by the instrument at the ambient atmospheric pressure of 731 torr.

[‡] SD = Standard deviation.

lot number and with the same certified nominal VAC (0.085 g/210 L \pm 2% at 760 torr) on three different dates spanning 9 days.

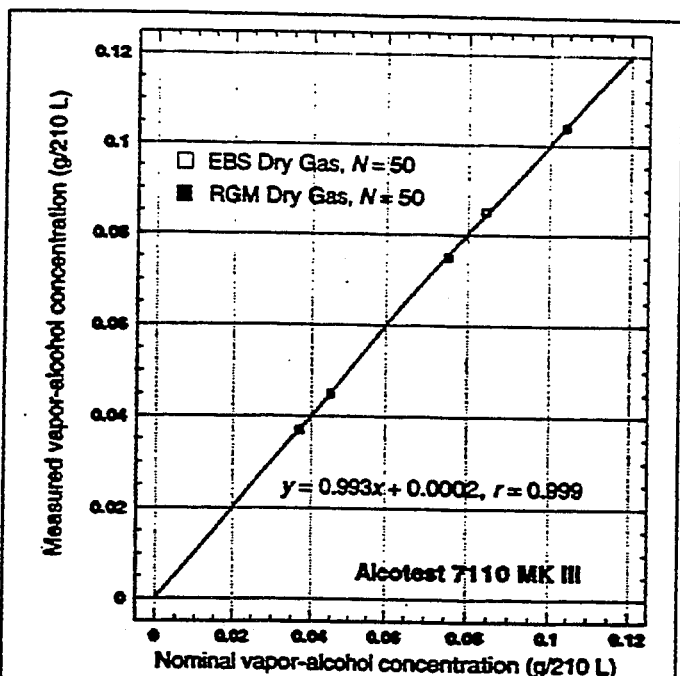


Figure 1. Correlation between nominal vapor-alcohol concentrations and mean measured vapor-alcohol concentrations of 50 within-run replicate measurements of dry gas controls (Ethanol Breath Standard [EBS] and Research Gas Mixtures [RGM]), using the Alcotest 7110 MK III evidential breath-alcohol tester (infrared channel).

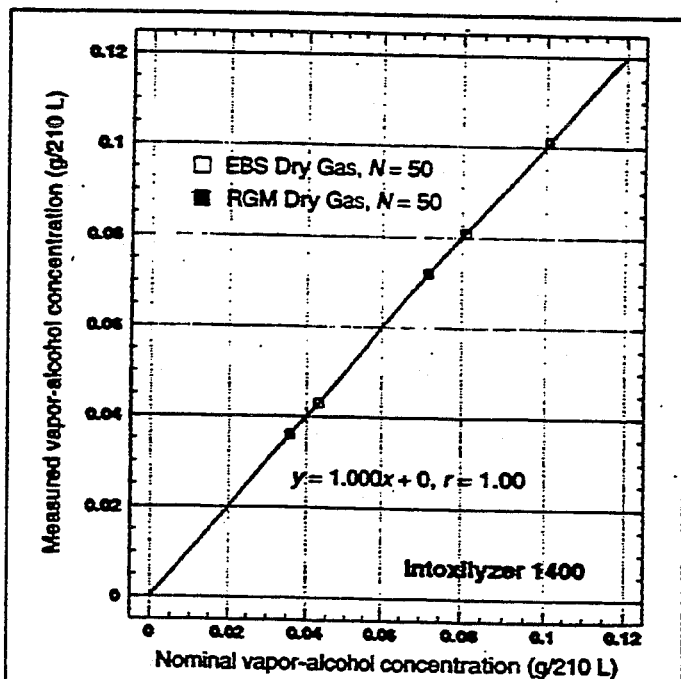


Figure 2. Correlation between nominal vapor-alcohol concentrations and mean measured vapor-alcohol concentrations of 50 within-run replicate measurements of dry gas controls (Ethanol Breath Standard [EBS] and Research Gas Mixtures [RGM]), with the Intoxilyzer 1400 evidential breath-alcohol tester.

Discussion

Control tests are a key element in a comprehensive QAP for breath-alcohol analysis (12). For ready determination of whether a breath-alcohol analyzer is performing properly, control tests must have predictable target values and yield consistent results that meet recognized criteria for validity and

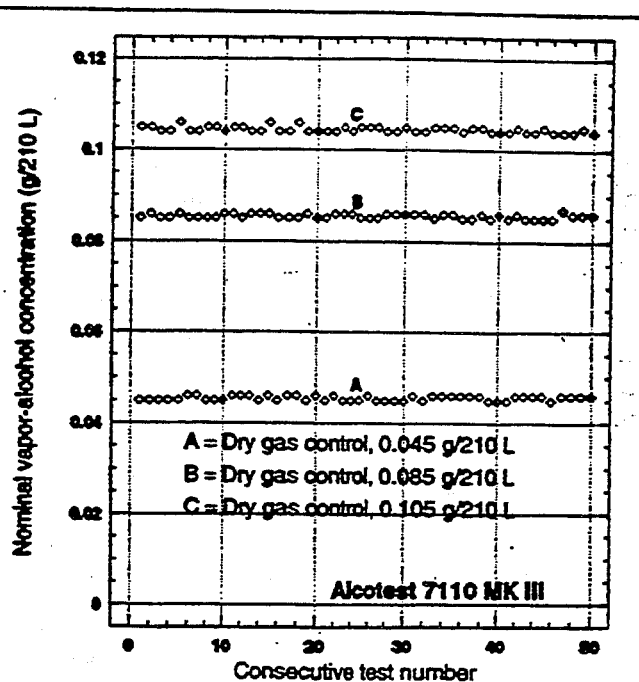


Figure 3. Results of 50 consecutive within-run replicate measurements of dry gas vapor-alcohol controls, using the Alcotest 7110 MK III evidential breath-alcohol tester (infrared channel).

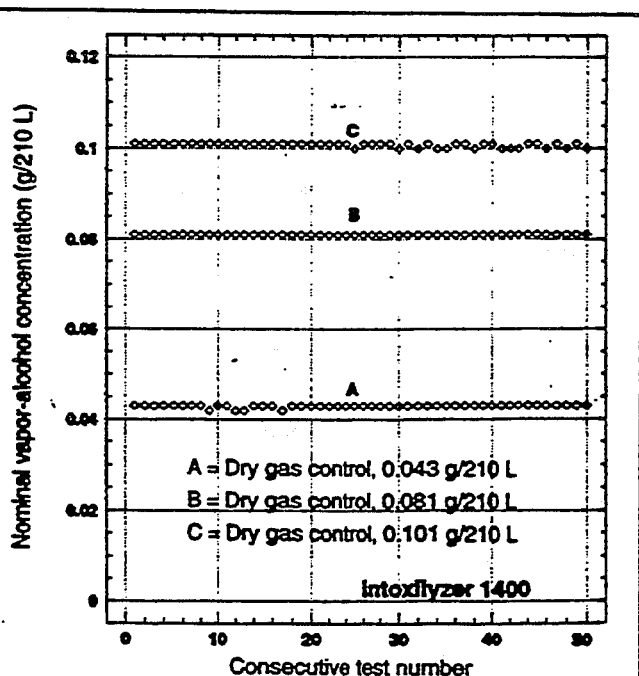


Figure 4. Results of 50 consecutive within-run replicate measurements of dry gas vapor-alcohol controls, using the Intoxilyzer 1400 evidential breath-alcohol tester.

acceptability. The results reported herein for dry gas control tests meet those requirements.

Several sets of acceptability criteria exist for the VAC values of calibrating materials (whether used for calibration or for control tests) and for vapor-alcohol measurements carried out with evidential breath testers on reference materials with established VAC values. The National Safety Council's Committee on Alcohol and Other Drugs has recommended that the results of vapor-alcohol control tests should agree with the established reference sample target value within ± 0.01 g/210 L and that the results of a minimum of 50 consecutive analyses with a quantitative breath-alcohol analyzer at any concentration within the 0.05–0.15 g/210 L span have a standard deviation not greater than 0.0025 g/210 L (13). Federal National Highway Traffic Safety Administration (NHTSA) model specifications for evidential breath testers require that VAC measurements at 0.020, 0.040, 0.080, and 0.160 g/210 L have an absolute systematic error not greater than ± 0.005 g/210 L (14). The manufacturer's QAP for the Intoxilyzer 1400 specifies that "the tolerance for an acceptable calibration verification is the chosen concentration ± 0.005 BrAC [breath-alcohol concentration] as displayed by the instrument" (15). The manufacturer's QAP for the Alcotest 7110 MK III states that "the maximum allowable accuracy tolerance is ± 0.005 grams per 210 liters of breath" (16). Vapor-alcohol measurements with the dry gas controls and with the analyzers used in this study fully met all three of these acceptability criteria, as applicable.

The validity of the VAC calibrations of the two analyzers was confirmed with both wet gas and dry gas RGM measurements as shown in Tables II and III, respectively. NHTSA has also recently proposed IR spectrometry as an alternate means for determining whether dry gas meets NHTSA model specifications for calibrating materials, which specify an absolute systematic error not greater than ± 0.002 g/210 L for measurements at 0.020, 0.040, 0.080, and 0.160 g/210 L (17). The most recent NHTSA conforming products list (CPL) of calibrating units for breath-alcohol testers does not list dry gas materials (17). Pending a revision of that CPL, the Secretary of Transportation has granted an exemption from the provisions of 49 CFR 40.55(a)(1) so that the EBS Gaseous Ethanol device can be used for "external calibration checks" by participants in the DOT-regulated workplace alcohol testing program beginning January 1, 1995 (18). The manufacturer's QAP for the Intoxilyzer 1400 requires verification of the calibration with "a standard whose concentration is between 0.020 and 0.100 BrAC with a tolerance of ± 0.002 BrAC" (15). The IR measurement results of the dry gas controls shown in Tables IV and V demonstrate compliance with both of these criteria, as applicable.

The results summarized in Table VI show that dry gas controls of the same lot from two different cylinders had identical VACs. Other tests of identical lots of dry gas at other nominal VACs and from different cylinders also showed full agreement of measured VACs. The between-run dry gas measurements summarized in Table VII yielded identical VACs and are typical

of other between-run tests in this study. The uniformity of dry gas VACs of given lots has thus been shown.

The VAC measurements reported herein were made at an elevation of 1225 ft (373.4 m). The results would be comparable with measurements at other elevations within the atmospheric pressure-sensing ranges of the alcohol analyzers used in this study. The atmospheric pressure-sensing range of the Intoxilyzer 1400 spans geometric altitudes from approximately 575 ft below sea level to greater than 10,000 ft; that of the Alcotest 7110 MK III spans geometric altitudes from approximately 1230 ft below sea level to greater than 9500 ft.

In contrast to the situation for aqueous alcohol solutions used in simulators, there is no reduction in the alcohol concentration of dry gas with continued use. In this study, we also found the effects of ambient atmospheric pressure variations on VAC measurements of dry gas to correspond very closely to those predicted by the physicochemical theory already discussed. We have thus validated both of the following practices: (A) comparing the results of experimental VAC measurements to predicted VAC values obtained by converting the certified nominal VACs at 760 torr to those at the properly measured ambient atmo-

Table VI. Within-Run Vapor-Alcohol Measurements of Dry Gas Controls from Two Different Scotty V Cylinders Using the Alcotest 7110 MK III

Number of tests	Detector	Nominal VAC* (g/210 L)	Measured vapor-alcohol concentration (VAC) (g/210 L) [†]				
			mean	SD [‡]	median	mode	span
37	IR [§]	0.044–0.046	0.045	0.0006	0.046	0.046	0.044–0.047
	EC		0.044	0.0008	0.045	0.045	0.043–0.046
20	IR	0.044–0.046	0.045	0.0006	0.046	0.046	0.044–0.047
	EC		0.044	0.0005	0.044	0.044	0.043–0.045

* The nominal VAC span at a standard atmospheric pressure of 760 torr for the dry gas lot-certified VAC value $\pm 2\%$.

[†] Results were normalized by the instrument to a standard atmospheric pressure of 760 torr.

[‡] SD = Standard deviation.

[§] IR = Infrared.

^{||} EC = Electrochemical.

Table VII. Between-Run Vapor-Alcohol Measurements of Dry Gas Controls from Three Different Scotty V Cylinders Using the Intoxilyzer 1400

Run	No. of tests	Barometric pressure (torr)	Nominal VAC* (g/210 L)	Measured vapor-alcohol concentration (VAC) (g/210 L) [†]				
				mean	SD [‡]	median	mode	span
1	53	723.6	0.079–0.082	0.081	0.0004	0.081	0.081	0.081–0.082
2	53	726.7	0.079–0.082	0.081	0.0005	0.081	0.081	0.081–0.082
3	50	722.5	0.079–0.082	0.081	0	0.081	0.081	0.081

* The nominal VAC span at ambient atmospheric pressure for the dry gas lot-certified VAC value $\pm 2\%$.

[†] Results were reported by the instrument at ambient atmospheric pressure.

spheric pressure at the time and location of the VAC measurement and (B) comparing the results of experimental VAC measurements normalized to 760 torr with the certified nominal VACs for 760 torr. The analyzers used in this study have sophisticated and versatile internal software and internal barometric pressure sensors that are capable of reflecting either pressure condition. We, therefore, chose to program the Alcotest 7110 MK III for VAC reporting at 760 torr and the Intoxilyzer 1400 for VAC reporting at the existing ambient atmospheric pressure. We conclude that both practices are feasible and valid, and we further conclude that the use of dry gas vapor-alcohol controls compares favorably with the use of simulator-generated vapor-alcohol controls for breath-alcohol analyzers that are capable of adjusting dry gas VAC results for ambient atmospheric pressure.

There is no current preference for either practice under federal regulations or through relevant scientific community agreement in the United States. The British Forensic Science Service (governmental) specifications for evidential breath-alcohol testing instruments require, with respect to dry gas use, that the temperature of the gas when introduced into the measuring system be at least 34°C, that the ambient atmospheric pressure be measured by an internal pressure sensor, and that the recorded ethanol concentration of the dry gas be automatically corrected to a standard atmospheric pressure of 101.3 kPa (equal to 760 torr) (19).

Lastly, it is relevant to reaffirm a key point concerning atmospheric pressure in relation to breath- and vapor-alcohol analyses. As indicated by the theory and borne out by the experimental results of this study, the expansion of compressed dry gas alcohol-gas mixtures to ambient conditions and, hence, the resultant VACs are partly controlled by atmospheric pressure. In contrast, the measurement of alcohol in breath is independent of the ambient atmospheric pressure (20), as is the evolution of wet gas from simulators and VAC measurements in wet gas samples.

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