

# Evaluation of Commercial Breath-Alcohol Simulators: Further Studies

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## Abstract

Exemplars of current commercial breath-alcohol simulators were studied to ascertain their suitability for control tests and as calibrators in breath-alcohol analysis. Temperature, effluent volumes and pressures, effluent-alcohol concentration, and alcohol depletion were measured for simulators coupled with various current alcohol analyzers. Effluent recirculation was found to extend the number of acceptable control test cycles by  $3.2 \times$  over nonrecirculation. We found substantial improvements in current commercial simulators and in their performance over those evaluated in 1979.

## Introduction

Breath-alcohol simulators are devices for equilibration of alcohol<sup>1</sup> between water and air at controlled temperature, commonly at 34°C. Originally developed to provide surrogate specimens for training breath-alcohol analysts, they have been widely used as calibrating devices for breath-alcohol analyzers and to produce control specimens for checking the performance of such analyzers. The alcohol concentration of the effluent vapor produced by a simulator is a function of the alcohol concentration of the aqueous solution and the equilibration temperature, in accordance with Henry's Law (1).

The scientific basis for and performance of breath-alcohol simulators were reported in 1979 by Dubowski (2). He demonstrated limitations and shortcomings in both design and performance of the commercial simulators then available and suggested improvements in design and use of simulators. In the ensuing decade, various improvements in simulator design and construction have occurred. We have, therefore, evaluated representative exemplars of current-generation simulators and here-with present our findings and conclusions.

## Experimental

**Breath-alcohol analyzers.** Production models of the following devices were employed, without modification: Model S-D2 Lion Alcolmeter (Lion Laboratories, Ltd., Barry, South Wales, U.K.);

Alco-Sensor III (Intoximeters, Inc.); Model J-4 A.L.E.R.T. (Alcohol Countermeasure Systems, Inc.); DataMaster II BAC Verifier (National Patent Analytical Systems, Inc.); Model 5000-D Intoxilyzer (CMI, Inc.); Model PAC 1200 Intoxilyzer (Federal Signal Corp.). All analyzers were calibrated to indicate g/210 L vapor alcohol concentrations, and the latter three instruments were used with factory calibrations.

**Breath-alcohol simulators.** Production models of the following simulators were employed: TOXITEST™ II Alcohol Breath Simulator (CMI, Inc.) and Model 34C Simulator (Guth Laboratories, Inc.). These devices are designed for a 500-mL alcohol solution volume and 34°C operating temperature, and were employed with factory temperature settings.

**Gas chromatography.** Alcohol was analyzed by automated gas chromatographic headspace analysis with a Model F-45 vapor space chromatograph (Perkin-Elmer Corp.), as previously described by Dubowski (3).

**Simulator temperature, volume, and pressure measurements.** Temperatures were measured with a Dignec Model HT 5810 digital electronic thermometer (United Systems Corp.) and a Model 703 thermolinear probe (Yellow Springs Instrument Co.). The thermometer and thermistor probe were calibrated against a NIST Standard Reference Material 934 mercury-in-glass thermometer (National Institute of Standards and Technology). Simulator effluent volumes were measured with a Wright Model MK12 respirometer (British Oxygen Co., Ltd., Pinacces, Essex, U.K.) and a Dräger Model 2217-10 Volumeter (North American Dräger). Simulator outflow pressures were measured with a Model 2050C Magnahelic direct-reading differential pressure gauge (Dwyer Instruments, Inc.). Simulators were operated with compressed air and regulated to produce 10 inches of H<sub>2</sub>O pressure at the simulator outlet, except when flow rates/pressures were controlled by the connected breath-alcohol analyzer, as noted in Table II.

**Simulator solutions.** Simulators were charged with 0.5 L of alcohol solutions prepared to yield target alcohol concentrations of the effluent at 34°C in accordance with Equation 1 (2):

$$y = 0.0415e^{0.065x} \quad (1)$$

$$r = 0.999$$

where  $x$  = Equilibrium temperature, °C;  $y = k_{aw} \times 10^3$  (Partition coefficient of alcohol for air/water  $\times 10^3$ ); and  $r$  = Pearson correlation coefficient. Thus, a solution containing 1.225 g alcohol/L

Table I. Static Temperature Observations on Commercial 34°C Breath-Alcohol Simulators\*

Mfr. & Model	Observed Temperature (°C)		
	Single random measurement	Mean of 5 measurements**	Mean & SD of 181 consecutive measurements†
CML Inc. TOXITEST II	33.94	33.95 (8)	33.98 ± 0.040 (7)
Guth, Inc. 34C	34.01	33.99 (6)	33.99 ± 0.008 (5)

\* Factory specifications = 34 ± 0.2°C and 34 ± 0.05°C for CML and Guth, respectively.  
 \*\* Temperature measured at 0, 15, 30, 60, and 120 minutes.  
 † Temperature measured at 1-min intervals.

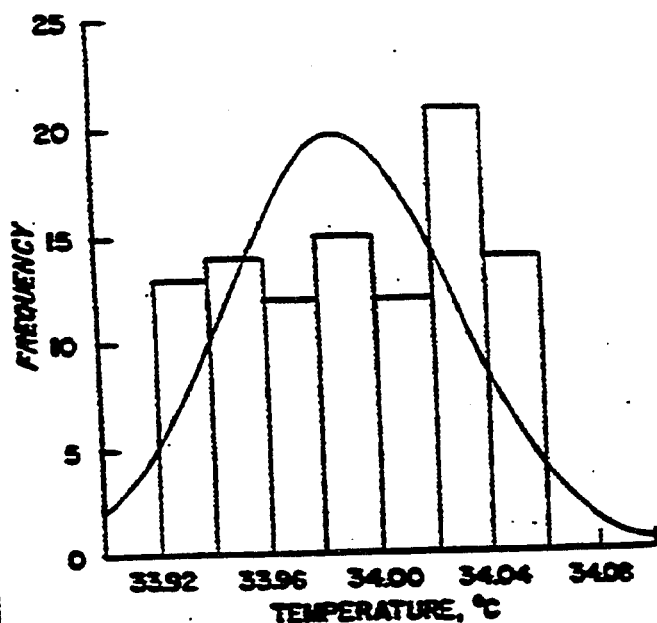


Figure 1. Frequency distribution of 181 consecutive static temperature measurements of the TOXITEST II simulator at 1-min intervals, with normal curve overlay

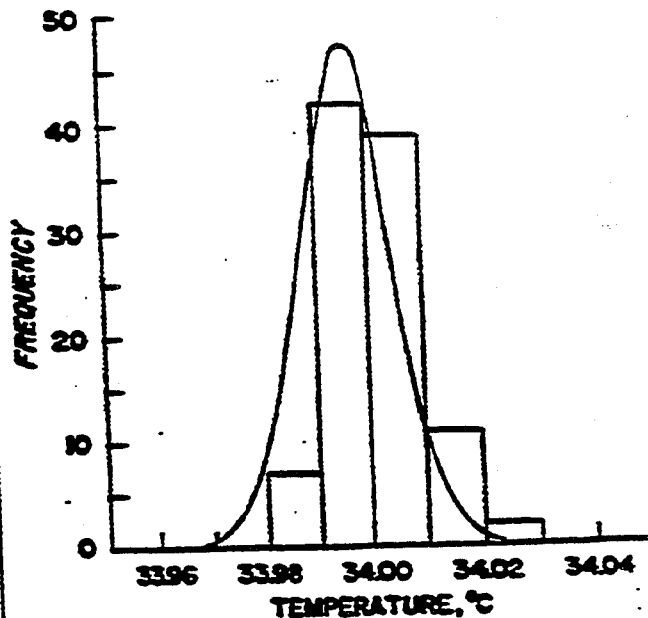


Figure 2. Frequency distribution of 181 consecutive static temperature measurements of the Guth 34C simulator at 1-minute intervals, with normal curve overlay

at 34°C will yield an effluent containing 100 mg alcohol/210 L of vapor ( $\approx 0.100$  g/210 L). The alcohol concentration of all simulator solutions was measured by gas chromatographic analysis before and after use.

**Statistical analyses.** Statistical examination and analysis of experimental data were carried out by standard statistical methods (4). The results of measurements of the vapor-alcohol concentrations of multiple simulator tests were subjected to linear regression analysis.

## Results

### Temperature fluctuation of simulators

The results of random and periodic static temperature measurements (i.e., without effluent production) on two commercial 34°C simulators are shown in Table I. The simulators remained undisturbed at ambient temperature (24.6°C) between measurements. Histograms of these measurement results, with normal curve overlays, are given in Figures 1 and 2.

### Breath-alcohol analyzer and simulator effluent parameters

Typical parameters for breath-alcohol analyzers and for simulator effluent are given in Table II for a Guth 34C Simulator coupled to several quantitative evidential breath-alcohol analyzers and screening test devices. The compressed air flow was regulated to achieve 10 inches of H<sub>2</sub>O effluent outflow pressure, except when otherwise controlled by the analyzer. All tests were performed in triplicate.

### Accuracy and precision of simulator-generated vapor-alcohol concentrations

The accuracy and precision of repeated within-run measurements of the alcohol concentration of simulator effluent with a target value of 0.10 g/210 L are illustrated in Figures 3 and 4, for TOXITEST II and Guth Model 34C simulators, respectively. The vapor-alcohol analyses were performed with a Model 5000-D Intoxilyzer, in the effluent-recirculation mode. The mean and SD values were  $0.100 \pm 0.0013$  g/210 L ( $n = 42$ ) for TOXITEST II simulator and  $0.100 \pm 0.0017$  g/210 L ( $n = 45$ ) for Guth 34C simulator. The "acceptable results" spans shown in Figures 3 and 4 reflect the accuracy (systematic error limit) requirements of both the federal NHTSA model specifications for

Table E. Breath-Alcohol Analyzer and Simulator-Effluent Parameters

Alcohol analyzer	Model	Nominal sample chamber Volume (mL)	Mean effluent volume per test (L)	Simulator outflow pressure, (in. of H <sub>2</sub> O)	Effluent flow time, (s)	Ethanol Depletion per Test <sup>1</sup> (mg)
Alcolmeter	S-D2	- 1.3	1.67	10 <sup>2</sup>	5 <sup>1</sup>	0.80
Alco-Sensor	III	- 1.3	2.25	10 <sup>2</sup>	5 <sup>1</sup>	1.07
ALERT	J4	- 0.4	1.06	10 <sup>2</sup>	5 <sup>1</sup>	0.50
BAC Verifier	DataMaster II	50	2.30	7 <sup>4</sup>	33 <sup>4</sup>	1.10
Intoxilyzer	4011AS-A	-400	4.08 <sup>4</sup>	4 <sup>4</sup>	33 <sup>4</sup>	1.94
Intoxilyzer	PAC 1200	39.6	0.52 <sup>4</sup>	4 <sup>4</sup>	20 <sup>4</sup>	0.25
Intoxilyzer	5000-D	81	2.00	5 <sup>4</sup>	17 <sup>4</sup>	0.95
			1.85 <sup>5</sup>	5 <sup>4</sup>	17 <sup>4</sup>	0.30 <sup>6</sup>

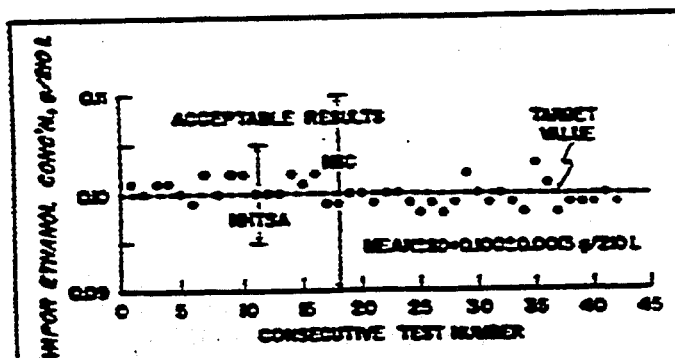
<sup>1</sup>Calculated for an effluent ethanol concentration of 0.10 g/210 L.<sup>2</sup>Effluent outlet pressure set at 10 inches H<sub>2</sub>O.<sup>3</sup>Effluent flow maintained for 5 s.<sup>4</sup>Pressure and flow time controlled by breath-alcohol analyzer.<sup>5</sup>In simulator effluent recirculating mode.<sup>6</sup>Calculated from results of consecutive tests: ethanol depletion study.

Figure 3. Accuracy and precision of consecutive measurements of effluent-alcohol concentration with the Intoxilyzer Model 5000-D and the TOXITEST II simulator.

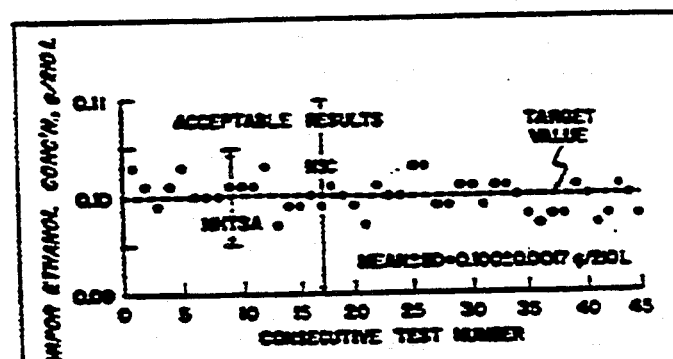


Figure 4. Accuracy and precision of consecutive measurements of effluent-alcohol concentration with the Intoxilyzer Model 5000-D and the Gm 34C simulator.

breath-alcohol measurement devices (5),  $\pm 5\%$  or  $\pm 0.005$  g/210 L at a concentration of 0.10 g/210 L, and the pertinent recommendations of the National Safety Council Committee on Alcohol and Other Drugs that the results of reference or control sample analyses for vapor alcohol should agree within  $\pm 0.01$  g/210 L with the sample value (6). Both of these requirements were met for every individual test on effluent from either simulator.

The between-run accuracy and precision of triplicate alcohol analyses of effluent from a TOXITEST II simulator with a target alcohol concentration of 0.12 g/210 L and performed with a Model 5000-D Intoxilyzer, in the effluent-recirculation mode, on 28 separate days, were as follows: For triplicate analysis sets ( $n = 28$ ), mean and SD were  $0.120 \pm 0.0013$  g/210 L, and the span of the means was  $0.118$ – $0.123$  g/210 L. For all individual analysis results ( $n = 84$ ), mean and SD were  $0.120 \pm 0.0017$  g/210 L, and the span was  $0.118$ – $0.124$  g/210 L. Again, both the NHTSA and the NSC Committee on Alcohol and Other Drugs systematic error limits were met for every individual measurement.

#### Depletion of alcohol in simulators

The effect of simulator effluent flow volume on simulators, used in the nonrecirculating analyzer mode, can be calcu-

lated from Equation II for the depletion phenomenon at  $34^\circ\text{C}$  (2):

$$y = 12.87x^{-1} \quad (\text{II})$$

where  $x$  = effluent volume per test (Liters) and  $y$  = number of tests yielding 1% depletion from the initial alcohol concentration of the simulator solution. The result yielded by Equation II for multiple tests is approximate, because the calculation is based only on the initial alcohol concentration of the simulator solution. The calculated quantity of alcohol lost per simulator test, for the stated conditions and at an initial simulator solution alcohol concentration of 1.225 g/L ( $\approx$  effluent alcohol concentration of 100 mg/210 L), is given in the last column of Table II.

Linear regression analysis of the results of measurements of the effluent-alcohol concentrations in multiple simulator tests yielded the following ratio for alcohol depletion of the simulator solution in repeated testing with the Intoxilyzer Model 5000-D:

$$\frac{\text{Alcohol Loss in Non-Recirculation Mode}}{\text{Alcohol Loss in Recirculation Mode}} = 3.2/1 \quad (\text{III})$$

Fifty consecutive simulator tests with the Intoxilyzer Model 5000-D reduced the alcohol concentration of the simulator so-

lution by 6.4% and by 2.0%, respectively, from the initial state for tests in the nonrecirculating mode and the recirculating mode under otherwise identical conditions.

## Discussion

The changes made by manufacturers in the design and construction of current commercial simulators from those available in 1979 include closer temperature regulation and better stirring of the simulator solution. Several other modifications proposed by Dubowski in 1979 (2), such as thermometers separate from thermoregulators and protection against overheating, have also been implemented. Those modifications have substantially improved performance of current commercial simulators over that of earlier devices. We have also evaluated several earlier models of commercial simulators and in 1988 reported the results of those studies (7). The present results again surpass the simulator performance reported by us in 1988, which was substantially improved over that reported by us in 1979.

The improved, appropriately narrow temperature regulation of the tested simulators is evident from Figures 1 and 2, and Table I. The frequency distribution of 101 temperatures of the TOXITEST II simulator solution, measured consecutively at 1-min intervals, approximates a uniform distribution, and that for the Guth 34C Simulator is a positively skewed normal distribution. Substantial temperature overshoots no longer occur in properly functioning current simulators, but air flow does produce additional temperature fluctuations beyond the static situation, especially if the air temperature is below 34°C. Clearing of the simulator headspace before use of the effluent remains a practical precaution. With properly fixed alcohol concentrations of the simulator solution, temperature fluctuations are the principal determinant of variability of the effluent alcohol concentration. Recommendations for preparing and validating alcohol reference solutions for simulator control tests in breath-alcohol testing have been adopted by the National Safety Council Committee on Alcohol and Other Drugs (8). They include the recommendation to establish the actual alcohol concentration of such solutions by appropriate analysis, using primary standards traceable to NIST standard reference materials.

The close control of effluent alcohol concentrations, reflecting the improved simulator temperature control, is evident in Figures 3 and 4. The cyclical rise and fall in vapor alcohol concentrations depicted is chiefly the result of temperature cycling of the alcohol solution. The numerical value of Ostwald partition coefficient  $k_{aw}$  for alcohol in the air/water system increases in value by 6.8% per degree C between 30° and 40° according to the data of Dubowski (2) and of Wells (9), and by 7.1% per degree C according to the data of Schoknecht et al. (10). The effluent-alcohol measurements reported above and illustrated in Figures 3 and 4 are subject to both systematic and random error from three sources: the simulator, the simulator alcohol solution, and the alcohol analyzer. Nevertheless, these experimental results are remarkably good.

Recirculation of simulator effluent is only feasible with nondestructive methods of alcohol analysis, such as infrared spectrometry. When it can be used, it has two desirable effects: It extends the useful life of the simulator alcohol solution, and it contributes to the reduction of alcohol concentration differences between individual effluent samples. The increase in simulator solution life produced by recirculation of effluent is substantial. The experimental results of multiple simulator tests and the regression analysis outcomes demonstrate that recirculation of the simulator effluent in the Model 5000-D Intoxilyzer can extend the number of acceptable control test cycles of a given simulator alcohol charge by 3.2x. Simulator solutions when used in a 34°C simulator do not, however, have an infinite life. There is some loss of alcohol because the system can leak, temperature differences cause condensation of water vapor from the effluent with consequent alcohol loss, and alcohol degradation can occur in the solution from microbial contamination.

The results of our evaluation demonstrate greatly improved performance of commercial simulators over those available a decade ago. Current generation simulators can be satisfactorily used, without tandem coupling, for calibration of breath-alcohol analyzers and for control tests.

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