A Depletion Compensated Wet Bath Simulator For Calibrating Evidential Breath Alcohol Analyzers

Slemeyer, A.

University of Applied Sciences of Giessen, Dept. of Electrical Engineering 1
Wiesenstr. 14, D-35390 **Giessen** / Germany
e-mail: andreas.slemeyer@e1.fh-giessen.de

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Abstract

Wet bath simulators have been in use for more than 4 decades for calibrating breath alcohol analyzers as they deliver a gas sample similar to human breath with regard to temperature and relative humidity. As the alcohol concentration in the liquid is depleted due to evaporation losses the solution has to be changed after a certain number of tests. This restricted their use in automated calibration systems.

The paper describes the design principle of a new wet bath simulator system that offers a long-term stable output concentration at a defined temperature. The compensation of the evaporation losses of ethanol in the liquid phase is done by replacing a certain amount of the simulator solution. The amount of fresh solution supplied after each test is depending on the volume of generated gas.

The Dräger ALCOCAL calibrator is the first instrument based on this technique. It has been approved by the German National Institute of Standards (PTB) in Braunschweig. Linking the ALCOCAL unit to a PC provides an automated operation which is very useful for production or calibration services.
The paper reports also on results from tests with the ALCOCAL.

Background

The OIML recommendation R126 for Evidential Breath Analyzers [OIML] sets high standards for calibrating evidential breath alcohol analyzers. It requires a sample of 3 l with a defined gas temperature of (34 ± 0,5) °C and a relative humidity of at least 95 %. The German Standard DIN VDE 0405 for Evidential Breath Alcohol Analyzers, released in 1995, follows the OIML recommendation, but introduces the breath temperature as a new parameter [VDE]. As the results of breath samples have to be referred to 34 °C, all measured concentration values are corrected by a temperature coefficient of +6.54 %/1 °C.

There are at least two conditions that are difficult to fulfill using compressed vapor-alcohol mixtures as a standard: high saturation with water vapor and precise gas temperature. This lead to the idea to improve the well-established liquid simulator system by designing a system for compensating the losses of alcohol due to evaporation.

Limitations of liquid simulators

Using a single liquid simulator with a water volume of 500 ml allows the delivery of only 10 to 15 l of test gas, until a 1 % depletion is reached [DUB-79]. As this is not acceptable for precision calibration purposes, OIML recommends the use of a "bubble train" of at least two cascaded wash bottles which are placed in a water bath of defined temperature. **Fig. 1** shows that such a 2-stage simulator can deliver about 6 times more test gas volume. To improve the long term stability OIML proposes a system, in which the solution in the first wash bottle is periodically replaced with fresh solution. Although this would help to keep up the concentration within the first simulator stage, there would be no precise information about the actual concentration in the second stage which is mainly responsible for the generated concentration at the output.

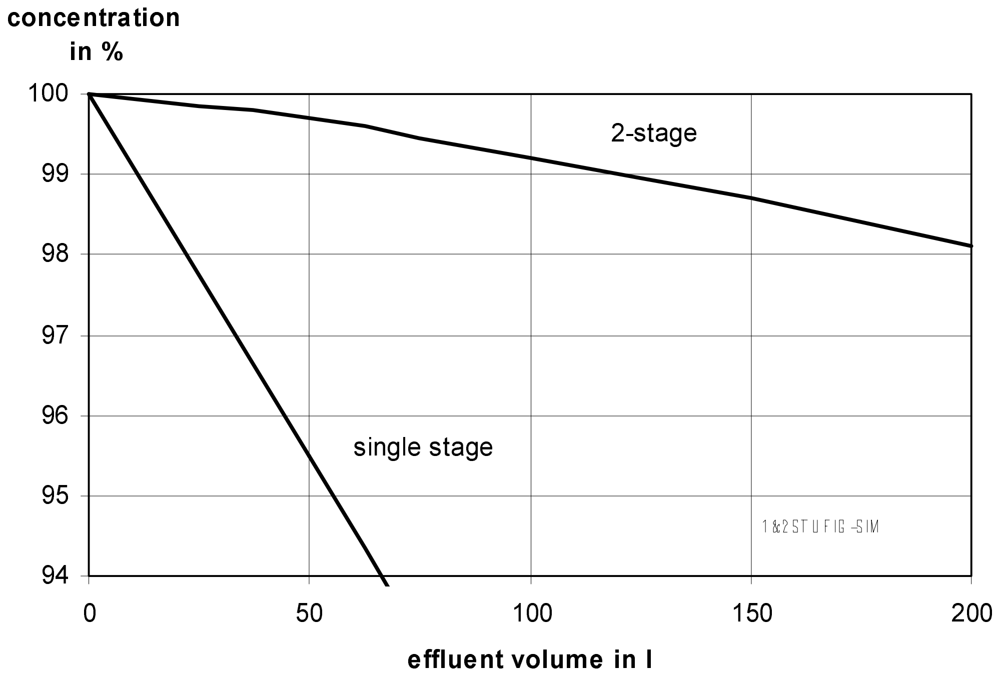

Fig. 1: Concentration drop using single and two stage wet bath simulators

The depletion compensation principle

This principle is based on the findings that the replacement of used simulator solution should take place in the last stage of the simulator. The drop in concentration due to evaporation is here much lower than in the upstream stage. Thus it requires a smaller volume of fresh solution to approach the former starting concentration level. This leads to a system in which the direction of flow of the simulator liquid is counter to the gas stream. The counter flow principle is known to be most effective among other exchange systems.

The amount of fresh simulator solution needed for maintaining a certain concentration level depends directly on the sample gas volume and the partition coefficient of ethanol between the liquid and the gas phase. If after each test a certain amount of fresh simulator solution calculated on the discarded sample volume is fed counter wise through the system, the output concentration can be kept within a very small range [PAT-1]. This has been shown by mathematical simulation and by experiments with several prototypes.

New simulator design

The main objective was to design a simulator system providing high long-term stability of the generated sample concentration. Other important features were:

- variable flow rates of up to 0.3 l/s
- variable sample volumes of up to 5 l
- temperature setting between 32 °C and 37 °C
- max. temperature drop during sample delivery: 0.1 °C
- automated compensation of the alcohol losses after each test
- remote control via RS 232
- automated procedures for replacing the simulator solution

To improve the temperature stability, especially at high flow rates, cylindrical containers are used which are coaxially disposed as shown in **Fig. 2**. The inner wash bottle is completely covered by the water column of the outer one which serves as a thermal insulator [PAT-2]. The electrical heating element is mounted in the outer wash bottle, whereas the actual temperature is controlled by a sensor placed in the inner vessel.

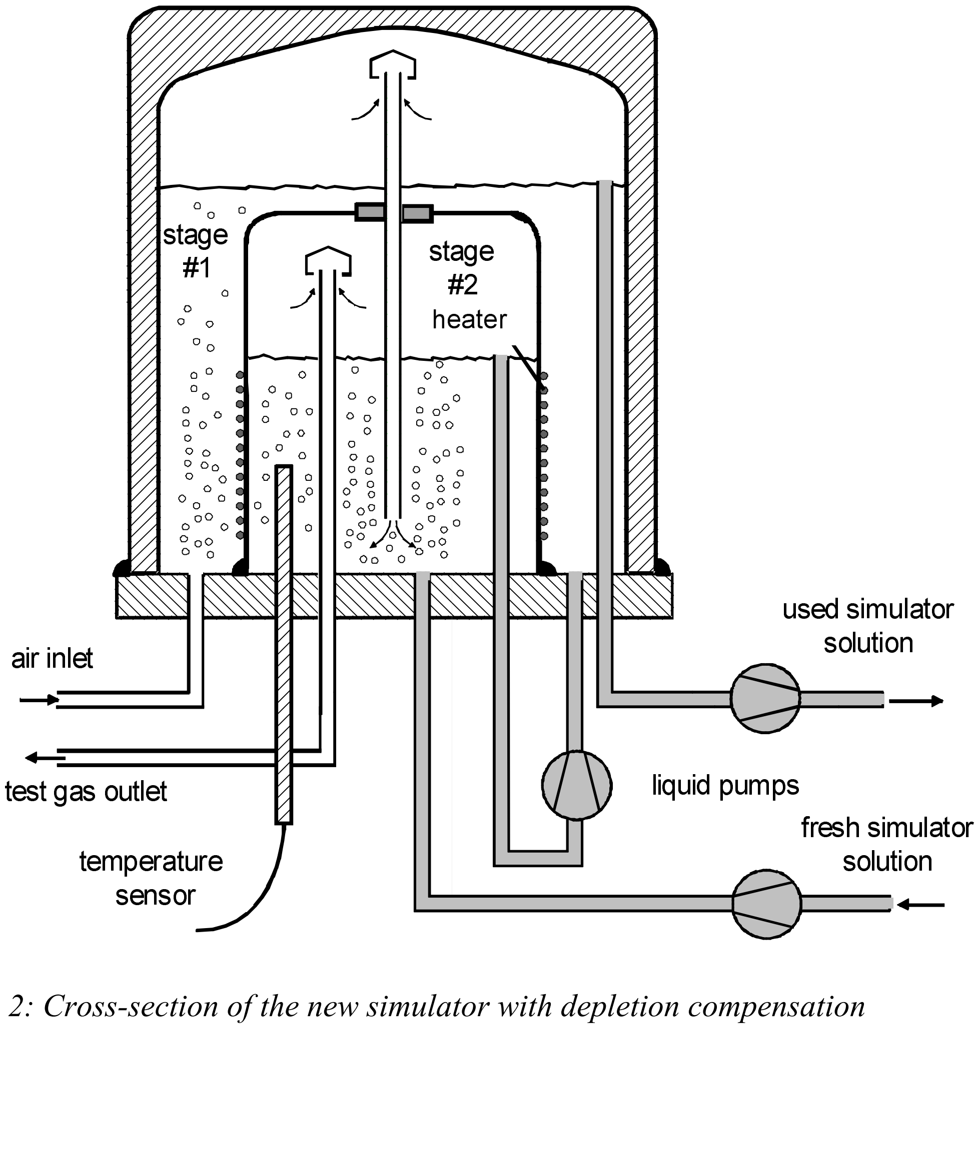

Fig. 2: Cross-section of the new simulator with depletion compensation

Both wash bottles are disposed on a common base plate with high thermal conductivity. All connecting lines run in the interior of this plate which is very close to the temperature of the simulator solutions. This is very important for the prevention of condensation within the gas conducting lines and for preheating the fresh simulator solution fed into the system. As the breath analyzer is connected directly to the outlet of stage #2, it will receive a test gas of the same temperature.

For the generation of gas samples of defined flow and volume a mass flow controller is used. Depending on the volume discarded for the sample a certain amount of fresh simulator solution is fed into the inner wash bottle after each test for compensating the alcohol losses. From there the overflow is pumped into the outer wash bottle which serves as the first simulator stage. Finally the overflow from the first stage is discarded into a container for used simulator solution. All pumps are controlled by liquid level sensors in order to detect any supply problems.

The above mentioned features were applied for the construction of the Dräger ALCOCAL simulator. It is the first industrial model of this new calibrator generation and has been approved by the German National Institute of Standards (PTB) in Braunschweig in 1999.

The ALCOCAL is equipped with a micro-controller which checks all functions of the instrument. A remote operation is possible by a serial interface. There is a special software for an automated calibration of the Dräger ALCOTEST 7110 Evidential analyzers. As it is possible to check all important calibration settings of the analyzer (concentration, flow and temperature) with one single instrument this simulator is a valuable tool for production lines or service centers. It is now in use at most of the agencies of the Federal Calibration Service in Germany.

Experiments

For demonstrating the repeatability and stability of the ALCOCAL calibrator tests were carried out at the German National Institute of Standards in Braunschweig in November 1999 using two ALCOTEST 7110 analyzers. The calibrator was set to 2 different temperature levels of 32 °C and 37 °C in order to check the slope of the concentration and temperature measuring systems.

For each temperature setting the calibrator was filled with fresh solution containing an ethanol concentration of 1,03 g/l. The sample volume was fixed to 3 l at a flow rate of 0,2 l/s, which led to a delivery time of 15 s. After each test the amount of 30 ml of fresh simulator solution was fed into the system for compensating the alcohol losses.

The analyzers were operated in the calibration mode which provides a third decimal place for the print-out , i.e. a resolution of 1µg/l. The concentrations were measured with the IR-sensor. To avoid additional sources of error they were not corrected for temperature. After each set consisting of 3 gas samples the calibrator output was switched manually to the other analyzer.

Results

Fig. 3 shows the result of 26 subsequent calibration tests using 2 analyzers. In this case the calibrator was operating at a temperature of 32 °C.

The span of the readings of both instruments was about 0,01 mg/l, which represents only 25 % of the allowed calibration error. There is no significant trend in the generated calibration concentration even after more than 50 tests which represent a volume of more than 150 l.

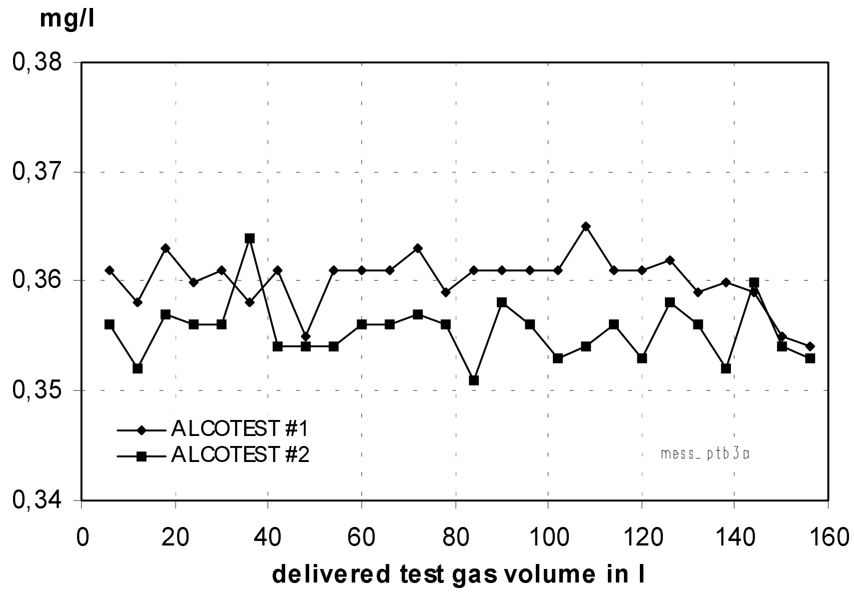

Fig. 3: ALCOTEST 7110 results with ALCOCAL set to 32 °C

A calculation of the linear trend line leads to a relative drop in concentration of $3 \cdot 10^{-3}$ per 100 l of test gas. This is due to the change of simulator solution and would not occur if the calibrator is continuously fed with a solution of constant concentration.

Table 1 compares some of the results of the tests at both temperatures. The total statistical errors of the measured concentrations are constituted by an overlay of different sources of influence. There is a small difference in calibration of both instruments, but their standard deviations are nearly identical. Their maximum value of 0,0028 mg/l is less than 50 % of the limit according to DIN VDE 0405.

The standard deviation appears to be independent of the measured concentration, which is a typical property of IR-analyzers. This is also expressed by a declining coefficient of variation at the higher concentration. deviation is mainly governed by the properties of the analyzers.

Table 1: Results from tests with ALCOCAL at different temperatures

	Tests at 32 °C		**Tests at 37 °C**	
	Alcotest #1	**Alcotest #2**	**Alcotest #1**	**Alcotest #2**
N	26	26	18	18
Mean in mg/l	0,3603	0,3556	0,5019	0,4924
SD in mg/l	0,0027	0,0028	0,0027	0,0026
CV in %	0,75	0,79	0,53	0,52

Discussion

Tests with the Dräger ALCOCAL have shown that the calibrator offers good long-term stability and repeatability of the generated alcohol concentration. This means that the applied design principles are very effective.

The high temperature stability allows a dynamic calibration of the temperature sensors of the breath analyzer. Due to its automated operation and the ability to operate on different temperature and flow levels this instrument is ideally suited for PC-controlled calibration systems.

Acknowledgments

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