Detection of Residual Mouth Alcohol Using Electrochemical Sensors

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Abstract

Residual mouth alcohol may be present if the deprivation period after the last drink has been less than 15 minutes. This is a typical situation for roadside testing or the use of personal screeners in restaurants and bars. As a result high false positive readings may occur evoking discussions about the usefulness of such devices.

Most of the instruments based on the effect of IR-absorption are able to detect this kind of interference by continuously monitoring the slope of breath alcohol concentration versus time. This can not be done with electrochemical sensors as their time constant for diffusion and electrochemical reaction is in the range of several seconds. So if a breath sample containing a very high residual mouth alcohol concentration is applied to an electrochemical sensor it would result in such a false reading.

The paper describes the new method of double sampling for detecting the presence of residual mouth alcohol. The technique is especially suited for breath testers using electrochemical sensors. Results from experiments with a wall-mounted breath tester applying this new technique are presented, underlining the usefulness in preventing false readings.

Introduction

Breath alcohol analysis is based on the evaporation of ethanol in the alveoli. So appropriate measuring would require a breath sample which is in equilibrium with the concentration in the deep lungs which is difficult to achieve under practical circumstances. In addition the ethanol concentration on the surface of the conducting airways and their temperature play an important role as they affect the constitution of the sample.

In this context mainly two kinds of influence are effective:

- physiological variations due to different ventilation patterns, e.g. hypo- or hyperventilation
- elevated ethanol concentration in the mouth and upper respiratory tract after the intake of alcoholic beverages.

While the influence of ventilation on the concentration of the expired breath can be reduced by measuring the breath temperature, a deprivation period of about 10 to 15 minutes after the last drink is normally required to avoid any influence of residual mouth alcohol on the constitution of the breath sample.

Fig. 1 shows the decay of the influence of residual mouth alcohol on the measured BAC (Breath Alcohol Concentration) as a result from drinking own experiments. Two subjects were tested under different conditions: one had a BAC of about 0,3 mg/l, the other one was sober. After taking 10 ml of vodka they were tested every 15 seconds with the Siemens ALCOMAT breath analyzer in the test mode.

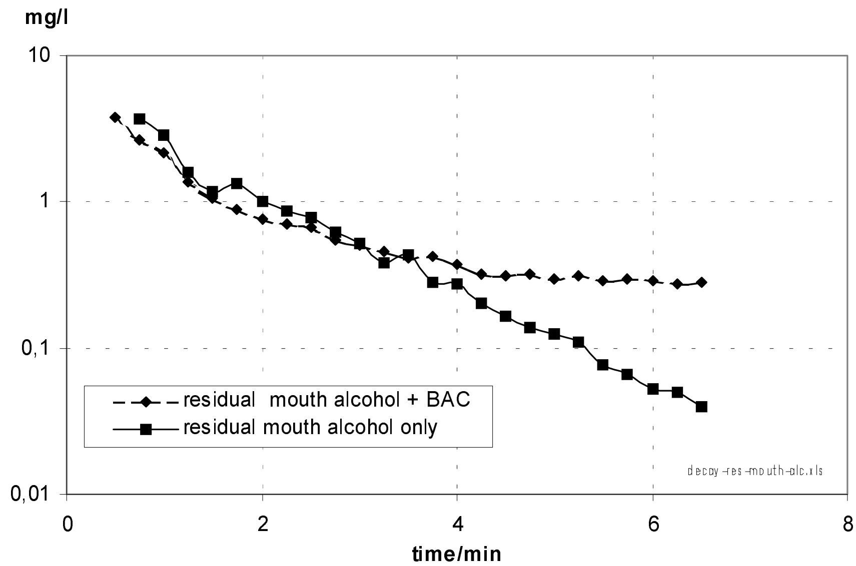

Fig. 1: Decay of the influence of residual mouth alcohol on measured BAC [PAU-99]

The expired peak concentrations of each test follow a semi-logarithmic curve versus time. After about 5 minutes the concentration approaches the actual BAC or continues to fall to the zero level. The peak level is mainly determined by the ethanol concentration, the amount of liquid and the time during which it was in contact with the mucous membranes of mouth and throat. The slope of the curve is nearly not influenced by these parameters.

Our experiments showed that a waiting period of 15 minutes is sufficient to exclude any interference of residual mouth alcohol. This is in accordance with current literature [GOS-68], [DUB-75], [KRÄ-87]. Under practical conditions like roadside testing or personal breath testing in bars it is very likely that the time between the last drink and the breath test is less than 15 minutes. So a correct breath test "on the spot" is not possible without additional technical countermeasures to detect the presence of residual mouth alcohol.

Detection of residual mouth alcohol

The profile of exhaled concentration versus time is affected by residual mouth alcohol. Under normal conditions the time course of the measured BAC is steadily increasing until it approaches the actual deep lung level. This means a steady positive, but decreasing slope. The presence of residual mouth alcohol may be detected by observing the slope of concentration during the delivery of the sample.

Under the influence of residual mouth alcohol this time course is altered depending on the time elapsed after the intake of the beverage. As the first part of the breath sample contains a higher concentration than the equilibrium concentration in the lungs, the time course shows a peak shortly after starting the exhalation. Due to the poorer diffusion conditions compared to those in the alveoli the concentration drops quickly and approaches the equilibrium level at the end of expiration. So a negative slope of the concentration time course indicates the presence of residual mouth alcohol.

The slope profile during exhalation under the influence of residual mouth alcohol depends on various factors like concentration of the alcoholic beverage, the time elapsed after intake, the actual breath alcohol concentration, the breathing pattern immediately prior to testing and also the breath flow rate. These various factors do not allow a 100 % detection rate for the interference caused by the presence of residual mouth alcohol. Nevertheless if clear signs could be detected, an indication would be very useful for the operator of the instrument.

A new approach for instruments with electrochemical sensors

Electrochemical sensors operate in a time-discrete mode by receiving single samples. So breath alcohol instruments using such sensors are not able to calculate the slope of concentration. The oxidation of ethanol molecules contained in a sample creates a time-dependent current flow. After a short rise to the peak the current drops following an exponential curve determined by the time-constant of the sensor. This means that high sample concentrations caused by residual mouth alcohol lead to high sensor currents and a prolonged recovery time.

The new technique consists in taking two samples for the electrochemical sensor: one shortly after the beginning of the sample delivery and the second one at its end [KÜH-95]. Detecting residual mouth alcohol would be possible by calculating their peak value ratio and comparing it with a given threshold. Under the influence of residual mouth alcohol it is to expect that the peak height of the first sample is higher, which means that the peak ratio is greater than 1.

There are technical limitations due to the non-continuous operation principle of the electrochemical sensor. If the first sample fed to the sensor contains high concentrations of ethanol, e.g. due to the presence of residual mouth alcohol or if the time between the samples is too short, it can occur that the sensor current has not returned to zero yet, before the next sample is taken. So the second peak would be superimposed to the tailing of the first one, as shown in **Fig. 2**. Here the breath samples were taken about 5 minutes after the intake of 10 ml of vodka, and the time difference (t_2 - t_1) between the samples was about 5 s.

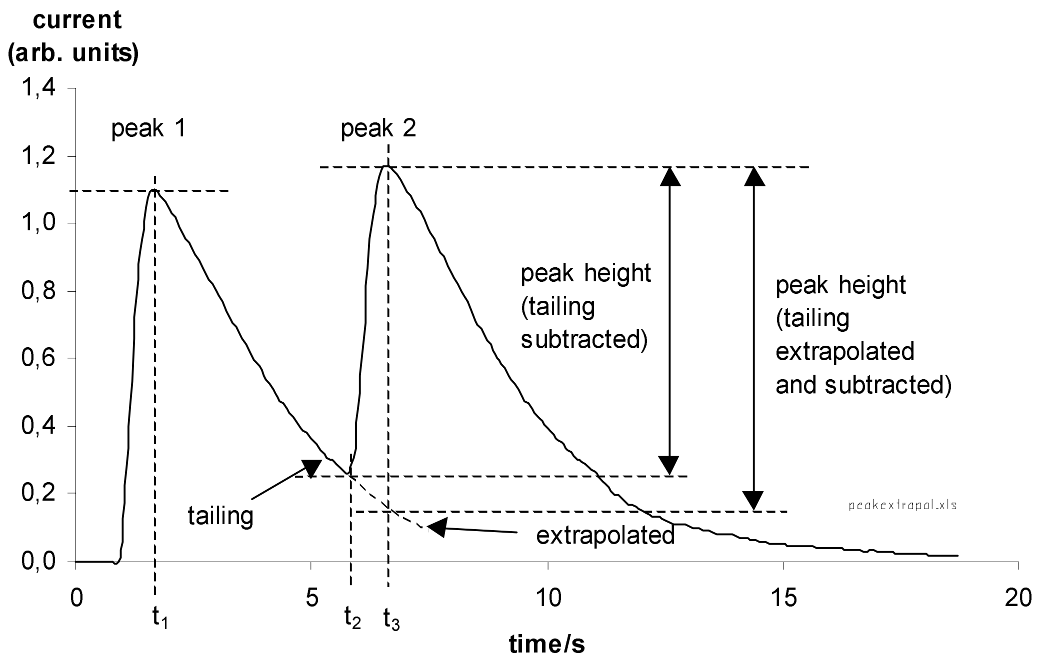

Fig. 2: Calculation of the peak ratio after double sampling

To compare the peak heights of both samples a first approach consists in subtracting the tailing from the peak 2 value. A more accurate method is to extrapolate the time course of the current from t_2 to t_3 where peak 2 occurs. Subtracting the calculated signal level at this point from the peak 2 value leads to the effective peak 2 height. This second method was preferred for calculating the peak ratios in our experiments.

Apparatus

Laboratory tests were carried out with a modified version of the "**Alkoholtester TN**", a wall-mounted personal breath tester designed for use in bars. The fuel cell-based prototype was equipped with a special software for double-sampling in order to detect the presence of residual mouth alcohol.

For a breath test the subject blows through a straw into a chamber from where the sample is aspirated by a pump and fed into the sensor. Due to the small dead space there are nearly no mixing effects which helps in resolving the high and fast changes in concentration.

The instrument is equipped with a flow sensor to check for correct sampling. After exceeding the minimum flow threshold the first sample is taken; the second one follows at the end of the sample delivery time. For the detection of residual mouth alcohol the software uses a fixed peak 1 to peak 2-ratio. If the measured peak ratio exceeds the value of 1.1 the indication "RES" (residual mouth alcohol present) is given. In this case the instrument uses a special purge procedure for cleaning the gas system.

Drinking experiments

The objective of our experiments was to find out whether the described method of double-sampling incorporated in the software of the "Alkoholtester TN" is effective to detect the interference of residual mouth alcohol.

Eight subjects volunteered in several sessions. They received small amounts of ethanol in form of beer or wine to achieve BAC levels between 0.1 and 0.4 mg/l. For generating elevated mouth alcohol concentrations the subjects rinsed their mouth with vodka for a period of 20 s and swallowed it afterwards.

To achieve favorable conditions for the detection of residual mouth alcohol the subjects were asked to keep their mouth shut and breathe through their nose during the time between two samples. The first breath sample was taken 2 to 3 minutes after the intake of alcohol. The sampling was repeated for the next 10 to 15 minutes until the display of the breath tester showed a constant reading.

The electrical signals of the fuel cell and the flow sensor were recorded by using a PC-based data acquisition system. The sample rate was set to 10 samples per second.

Results

During our experiments more than 90 tests were recorded. Within the first 10 minutes after alcohol intake the detection rate was only 20 to 30 %. It declined with the time elapsed, as expected. In some cases a concentration value was indicated although the calculated peak ratio was clearly above the threshold. defined in the software. In spite of the high concentrations, especially shortly after the intake, the fuel cell was able to recover in about 1 minute which allowed a short test sequence and up to 12 tests within a period of 15 minutes.

Fig. 3: Peak ratio as a function of the time elapsed after alcohol intake

Fig. 3 gives an example of the calculated peak ratios as a function of time for 3 different subjects. High fluctuations of the peak ratios occurred within the first 10 minutes. The threshold value of 1.10 fixed in the software of the Alkoholtester is reached for the first time after 5 minutes. This explains why the mean detection rate was only about 20 % during this period of time. After 9 minutes nearly all peak ratios were lower than the fixed threshold.

For the period from 10 to 15 minutes the ratio is still decreasing and reaches a value between 0.80 and 0.90. It is to expect that with a future threshold value between 0.90 and 0.95 the detection rate will be much higher. This can be shown by the calculated ratios contained in **Tab. 1**.

Tab. 1: Concentration values and calculated peak ratios as a function of time. (RES: residual mouth alcohol detected)

elapsed time	L. (female)		D. (female)		C. (male)	
in minutes	mg/l	peak ratio	mg/l	peak ratio	mg/l	peak ratio
3			**RES**	1,25		
4					1,24	1,22
5	1,46	1,36	**RES**	1,12	0,99	1,00
6					**RES**	1,31
7	0,72	1,08	**RES**	1,10	**RES**	1,08
8	0,73	0,91	0,22	1,01	0,23	0,98
9	**RES**	1,22	0,19	1,05	0,22	0,96
10			0,18	0,97	0,19	1,00
11	0,49	0,88	0,17	0,91	0,17	0,83
12	0,46	0,94	0,15	0,89	0,15	0,87
13	0,41	0,90	0,15	0,86	0,15	0,84
14	0,41	0,86				
15	0,40	0,82				

Table 1 shows that during the first 8 minutes in only 5 out 24 tests the sign "RES" occurred, although the calculated peak ratio was always higher than 0.90. and in most cases greater than 0.95. It seems that there is some correlation between the changes in concentration and the peak ratios. With smaller changes in concentration, the peak ratios approach a value of about 0.9. For the time period after 10 minutes small concentration changes are still noticed, but less than 10 % of the actual reading.

Discussion

Breath tests with the "Alkoholtester TN" have shown that the method of double sampling is suitable for the detection of residual mouth alcohol. The decision is based on a comparison of the calculated peak ratio with a threshold value. The described method could also be used with other time-discrete measuring systems than the tested fuel cell. An important advantage is that no additional hardware is needed.

In our experiments the breath tester showed only low detection rates of about 20 to 30 % within the first 10 minutes after alcohol intake. This was probably caused by the software which was programmed for a threshold of the peak ratio of 1.10. Calculations based on the recorded data show that if this threshold would be reduced to 0.95, a substantially higher detection rate could be achieved. In addition the time interval for detection could be extended to up to 12 minutes.

All tests took place under conditions that favored the occurrence of residual mouth alcohol interference. It is to expect that under practical circumstances the detection rate is lowered by uncontrolled ventilation effects prior to the sampling. Nevertheless the described method is of practical value for screening purposes or self-testing by preventing gross errors in the determination of the actual breath alcohol concentration.

The results showed also that a 15 minutes waiting period is still necessary for forensic measurements in order to exclude any influence on the measured BAC.

Acknowledgments

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