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Scientific Principles of Evidential Breath-Alcohol Testing Up-to-date Technologies and Procedures

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Abstract

To ensure traffic safety, law enforcement dedicates considerable time & resources to control drunk-driving (DUI, driving under the influence). It is often questionable whether the law is carried out properly and due process followed. Therefore, it is necessary for us to consider more appropriate and more advanced breath analytical procedures of other, more DUI experienced countries.

It will be demonstrated through advanced scientific knowledge the deficiencies in the current breath alcohol testing programs and the equipment in use. Legal guidelines and applicable per-se-laws set the legal stage in most industrialized countries, yet, regulations, procedures and laws in other countries often lack sufficiency and complexity. This causes lack of faith by the subjects, prosecutors, judges and forensic experts regarding the program guidelines and the equipment in use. Often, the alcohol offender asks for a second test or challenges the system's analytical capabilities and integrity.

To improve the total program, research is directed to evaluate advanced and evidentially solid breath test programs and technologies in use. In summary, this paper's conclusion shall guide the program administration in implementing state-of-the-art standards and regulations for modern, evidential breath alcohol analysis and procedures for the police forces.

1.Introduction

Many humans are attracted to the psychoactive effects of alcohol on the body thus, it is the most common, legal (in most countries) drug of choice. However, the influence of alcohol or the over-consumption of alcoholic beverages by humans is often the cause of crimes and violence, including fatal traffic accidents. Worldwide, five percent of all deaths of people in the age group 5 to 29 (1990 National Highway and Traffic Safety Administration, NHTSA statistics) were attributable to alcohol use. Traffic deaths rank highest among all causes of death & alcohol related traffic fatalities rank highest within this category. Law Enforcement Agencies are challenged to locate intoxicated drivers and to remove them from the public roadways.

In the late 1940's, the forensic community was challenged to search for more objective, non-invasive methods to determine a vehicle operator's impairment level and ability to safely operate a vehicle on public roads. While analysis of bodily fluids such as blood or urine for measuring the subject's intoxication levels are scientifically suitable, the sample collection is invasive for the subject, the analytical process is costly and not appropriate for

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handling by police forces. Its analytical inefficiency is further accentuated because its processes require additional laboratory personnel and elaborate analytical instrumentation (GC and/or MS).

Consequently, the analysis of alcohol in breath was considered a very desired and objective test specimen for determination of a vehicle operator's breath-alcohol concentration and impairment level for evidential purposes. In the early 1950s, the Breathalyzer® 900 set the basis for the scientific acceptance of analyzing alcohol in breath. Law-Enforcement personnel implemented and administered these noninvasive and efficient tests as part of their drunk-driving enforcement. Furthermore, it allowed the criminal justice system to set the basis for conviction of subject's who have exceeded punishable limits of alcohol concentration in their body.

2. Technical Challenges for Breath-Alcohol Testers

Physiological factors and the dynamic factors in the expired breath's composition have been challenging the research and manufacturing community to produce the best scientific breath testers possible. In addition, it is required that a breath tester's integrity can't be influenced by the operator's or the subject's actions, cooperation or limitations. Foremost, an evidential breath-alcohol tester must comply with local laws and local specifications, be accepted in the forensic community, and be scientifically reliable to stand firm against all facets of court challenges brought upon by the legal defense.

A Physiological Aspects

Significant physiological factors which can affect the validity of a breath test measurement must be considered by the instrument when utilized in evidentiary and legal applications. It must be noted that "Standardized Operator Procedures" can reduce the occurrence of certain physiological effects:

- Vital lung volume versus expired breath volume.
  It is essential that the breath tester samples only the end of a prolonged exhalation (alveolar air) for analysis. Sampling and measurement of pre-alveolar breath will give measurements which aren't in equilibrium with the actual blood alcohol concentration.
- Mouth-alcohol.
  Mouth-alcohol represents high concentration, residual alcohol in the mouth cavity from the beverage consumed or use of alcohol containing medication or breath spray. Such measurements lead to falsely high readings. In addition, the "Standardized Operator Procedure" should mandate a > 15 minutes wait period prior to any evidential breath test.
- Regurgitation of stomach contents.
  Vapors stemming from regurgitation (burping) are of extremely high alcohol concentration. Unfortunately, even a 15 minute waiting period cannot prevent this situation. This phenomena leads to erroneous high alcohol measurements and must be addressed when testing for legal purposes.
- Breathing patterns.
  A subject's breathing pattern prior to the test can greatly alter the breath test result. Rapid inhalations and exhalations (hyperventilation) by the subject either intentionally or because of nervousness will lower the exhaled breath temperature

thus, lower the breath-alcohol measurement. Contrary, a subject holding the breath (hypoventilation) prior to the test will increase the breath temperature thus, increasing the expired alcohol in breath. The ambient air temperature in the testing vicinity can magnify this effect due to the cooling or warming of the upper respiratory system.

- Breath temperature.
  It has long been assumed that a subject's exhaled breath temperature is at a steady 34°C. However, rather recent studies suggest that the average breath temperature is between 34.5°C and 35°C. Thus, deviation of the actual end-respiratory breath temperature from the assumed 34°C will either over or underestimate the true alcohol measurement by 6.58% per one degree Celsius. Breath temperature variations can be influenced by subjects exposed to hypothermia/hyperthermia, fever, hey-fever, menstrual cycles, ambient temperature, anxiety, hypo- and hyperventilation, etc.

These test dynamics must be addressed by breath-alcohol instruments if used for legal and evidentiary testing. Most recent developments in evidential breath-alcohol instruments incorporate monitoring and sensing features which monitor these physiological and influential factors.

3. Technology-History of Breath-Alcohol Analyzers

The technology of breath-alcohol testing has changed fundamentally over the years. This was partially driven by general technology advancements and in part due to defense challenges. The most evolutionary advancements in technology can be seen predominantly in Western, industrialized countries where evidential breath alcohol testing started over 50 years ago. The following is a chronicle describing the most recognized technologies used for preliminary ("screening") and evidentiary breath-alcohol analysis as well as its advantages and disadvantages:

A. Wet-chemical Oxidation technology:
   The first significant breakthrough in evidential breath testing technology began with the Breathalyzer® 900 in 1954. The analytical principle was based on chemical oxidation by alcohol within a mixture of dichromate and sulfuric acid in vials. It paved the way for scientific acceptance of evidential breath alcohol testing by the international forensic community and the courts.

   Advantages:
   - Compact table-top package.
   - Relatively quick analysis.
   - Accurate and specific to alcohol.

   Disadvantage:
   - Minimum required breath volume < 60mL.
   - The handling of the vials is critical as they contain sulfuric acid.
   - The Breathalyzer's biggest short-coming however, was the fact that the system was operator dependent.
   - Growing legal attacks in the eighties rendered the Breathalyzer® 900 vulnerable to manipulation by the operator thus; the equipment was rapidly replaced by newer and less operator dependent instruments.
   - The last Breathalyzer® 900 was manufactured in 1992.

- Currently, there are still about 500-700 instruments in operation mainly in the State of New Jersey, USA and a few in Canada.

B. Solid-state sensor technology:

Commonly called "Taguchi" cells, a metal oxide semiconductor based sensor manufactured by Figaro located in Japan. The Taguchi cell operates by adsorption of gas molecules on the surface of a semi-conductor. This transfers electrons due to the differing energy levels of the gas molecules on the semi-conductor's surface.

These types of instruments are sold mainly to the consumer markets as opposed to law enforcement. None of these sensor-type instruments are approved by the National Highway Safety Administration as evidential breath testers.

Advantages:

- The sensors are small in size and rather inexpensive to manufacture. Lowest priced breath testers.
- These instruments are sold in convenience stores and mail-order-catalogs.

Disadvantages:

- The sensor is very unstable, drifty and non-specific to alcohol.
- It reads all hydrocarbons (organic vapors) and will habitually produce false positive alcohol readings caused by smoker's and car exhaust CO as well as many other environmental vapors and gases.
- This senor is partial pressure sensitive and therefore changes sensitivity with change in altitude and elevation.
- This sensor is sensitive to changes in ambient temperature, humidity and breath-flow patterns.
- For these and other reasons, solid-state sensor instruments can't be employed in evidential and legal applications.

C. Electro-chemical cell technology ("EC"):

Most commonly called "fuel-cell". Fuel-cell technology for alcohol analysis was first introduced in the early 1970s by an Austrian researcher. The EC sensor requires a sampling system consisting of a piston or bellow pump assembly, applying a very precise amount (~ 1 ccm) of breath to the sensor. The volume consistency is highly important because the current produced by the sensor is proportional to the total number of alcohol molecules converted in the sensor. The sensor is composed of an immobilized electrolyte, flanked by an active and a passive electrode. The electrolyte and the electrode material are selected such that the alcohol to be measured is electrochemically oxidized and converted at the active electrode. The change in the electronic conductivity causes a rise in current flowing from the active to the passive electrode. The total electrochemical reaction is evaluated by time integration of the sensor's current. This analytical process is referred to as coulometry. A further benefit of this method is the test result stability throughout the sensor's life. The sensor's life expectancy is approximately 4-5 years.

Advantages:

- The sensor is highly specific to alcohol.
- The measurement cannot be biased or influenced by endogenous substances such as acetone (diabetics and starving people), CO or Toluene.

- The sensor is highly sensitive, down to 0.1 ppm.
- Accuracy meets specifications for evidential instruments (NHTSA) and remains stable ≥ 6 months before having to calibrate it again.
- Its expected life term is approximately 5 years.

Disadvantages:

- EC based instruments cannot observe the breath alcohol concentration throughout the subject's exhalation (see "Physiological Factors" above). This doesn't allow detection of alveolar breath ("deep lung air"), mouthalcohol, belching, burping, Gastro Esophageal Reflux Disease (GERD) and residual alcohol trapped under dentures or alcohol from bleeding gums.
- The EC sensor is cross sensitive to other alcohols such as methanol and isopropanol.
- The EC sensor's output is temperature dependent and suffers short term fatigue if the sensor is exposed to a series of successive alcohol containing tests.
- EC based instruments are not accepted for evidential use in many countries, states and jurisdictions.

D. Infrared Spectroscopy ("IR"):

IR technology (IR Spectra-photometry) based breath-alcohol testers were first introduced in the mid 1970s. IR instruments have become the standard worldwide for legal, evidential breath analysis.

The analytical concept is based on the Beer-Lambert Law of physics, the "Law of absorption". It addresses the linear relationship between absorbance and concentration of an absorber of electromagnetic radiation. Alcohol vapor introduced into an absorption chamber will absorb some of that IR radiation transmitted through the chamber. The amount of IR absorption is in direct proportion to the quantity of alcohol present (breath-alcohol). However, only IR-radiation of a specific wavelength will absorb alcohol. The two predominantly utilized wavelengths are centered at 3.39 and 9.5 µm. From this technology's inception, the IR absorption wavelength was in the 3.4 µm range. The latest generation instrumentation monitors IR absorption at 9.5 µm because the measurements are far less prone to interference from any hydrocarbons and acetone which absorb IR energy at 3.4 µm.
The most significant benefits of "real-time" IR absorption analysis (continuous measurement) requires understanding the dynamics of alcohol in the human breath. Some of these dynamics relate to gas exchange in the mucus membranes, residual alcohol in the upper respiratory tracks, belching, burping, Gastro Esophageal Reflux Disease (GERD), exhaled air volume, breath flow rates and the subject's breathing pattern.
Only IR technology is capable of addressing these dynamic, physiological factors to determine a legitimate, rightful and legally as well as forensically justifiable breath-alcohol measurement.

Advantages:

- IR based equipment observes the breath-alcohol concentration throughout the subject's exhalation. This allows the plot of the entire IR-absorption curve and the instrument's intelligence to assure that:

    - The breath sample was of alveolar nature
    - No residual or mouthalcohol was present
    - The subject did not belch, burp or experience GERD
    - The recorded absorption curve can be presented in court if the case is challenged
- The IR system does not have a limited life expectancy, will not fatigue with successive, high alcohol concentration test series and remains extremely stable for years.
- These instruments are equipped with many other important peripherals and functionalities (please observe “Other required performance features for evidential breath testers” below)
- IR instruments are today’s standard worldwide for legal, evidential breath-alcohol analysis and consequently face fewer legal challenges than all other breath testing devices and technologies.
- The following international standards highlight IR technology in their specifications:
    - OIML, Europe
    - NHTSA, USA
    - CSA, Canada
    - AS, Australia
    - Numerous country specific requirements.

Disadvantages:

- IR instruments are larger in size thus, not suitable for portable, handheld operation.
- These instruments are more expensive than handheld (screening) equipment employing solid-state or EC sensors.

4. Additional Performance Requirements For Evidential Breath Testers

Evidential breath tests are prone to criminal defense challenges simply because its results may have legal consequences for the person accused of having offended laws or statutes. The legal defense community therefore contests the authority’s overall program quality, the integrity of the breath tester and the test-administration. This condition encouraged instrument manufacturers and program administrators to relentlessly expand and improve upon their applied methodology and the applied analytical technology. The following IR-instrument features are incorporated and standard in all advanced and well established, international, evidential breath test programs:

A. Observation of a Deprivation Period:
Adapted by virtually all evidential breath test programs, a deprivation or observation period of at least 15 minutes is required prior to the test. This eliminates any potential interference by recently ingested alcohol residing in the oral cavity and upper respiratory system. Sources of residual alcohol include beverages, mouth sprays, medication, breath deodorants, etc. Some jurisdictions require a time-down-counter by the instrument to assure that the breath test cannot initiate prior to observing the subject for ≥ 15 minutes.

B. Air Blank Test:
An ambient air check should be performed prior to an evidential breath test. The significance of this test is to eliminate the possibility of an exogenous substance in

room-air interfering with the breath test. Such substances include exhaled breath-alcohol from subjects waiting to be tested, air pollutants, solvents, finger-print wipes, etc. This feature ensures proper purging of the absorption chamber and the imperative zeroing of the IR detection system prior to a subsequent analysis. The breath test instrument analyzes the ambient air for any absorbing substance, alerts the operator of an interferent in the air, and halts the continuation of the test sequence.

C. Heated Breath Paths:
All tubing, hoses, absorption chamber, valves and any other breath-passages shall be heated to > 39 degrees Celsius to prevent internal condensation. Condensation may result in low readings (alcohol being trapped) or wrongful positive readings (release of trapped alcohol). Furthermore, correct heating and the temperature shall be monitored by the instrument and the instrument shall disable itself if the temperature is out of range.

D. Duplicate Breath Analysis:
Most jurisdictions and international breath test standards (incl. OIML) mandate the analysis by two independent measurements of duplicate breath samples. The two breath tests should be part of the instrument's automatic test sequencing and > 2 minutes, but < 10 minutes apart. The purpose of duplicate analysis is to further suppress any potential bias due to RFI, mouth alcohol, instrument failure, intermittent errors). Both test results shall be within acceptable agreement in order to validate the test. The lowest of the two readings is commonly used for legal reporting.

E. Mouthalcohol Detection
The potential presence of Mouthalcohol has been a popular defense maneuver in court for decades. Real-time observation of the IR absorption curve by a sophisticated algorithm can detect the presence of residual mouthalcohol. "Mouthalcohol" includes alcohol sources from recently ingested alcoholic beverages, trapped alcohol under dentures, alcohol in blood from bleeding gums and tongue/lip/cheek piercing, belching, burping, GERD, etc. Only IR based breath testers can detect mouthalcohol.

F. Slope Detection
"Slope" detection refers to the IR absorption profile generated during the delivery of an alcohol containing breath sample. At the beginning of the exhalation the absorption is near zero. As exhalation progresses, the breath-alcohol-concentration increases rather sharply and as the air from the alveolar region of the lungs reaches the system the concentration increase slows down significantly. In other words, once alveolar air reaches the IR chamber, the absorption slope becomes nearly level. The instrument's algorithm observes the IR absorption slope from the beginning to the end of the subject's exhalation. If the breath-alcohol-concentration is still increasing at a rate greater than specified (at the time the subject stops blowing into the instrument), the test will be nullified and must be repeated. This is a fundamental analytical feature of evidential breath testers.

G. Minimum Exhalation Volume
The preferred specimen for breath analysis is expired alveolar breath as it represents most reliably the subject's actual blood alcohol concentration. International forensic scientists suggest that a minimum breath volume of 1 – 1.5 liters must be delivered

before the sample is taken for analysis. A subject's maximum exhaled breath volume (vital capacity) can vary from approximately 2 – 7 liters, depending on physical condition, gender and age.

H. Minimum Exhalation Time
Requiring a minimum exhalation time reduces the risk of creating to much back pressure during the exhalation process. Excessive back pressure would influence the alcohol concentration due to the partial pressure difference in the lungs versus the ambient pressure.

I. Breath Temperature Compensation
The breath-alcohol-concentration is expired breath- temperature dependent. The temperature coefficient of alcohol solubility for solutions in water and biological media is 6.5% per degree Celsius change (Harger et al., 1950a; Jones, 1983a). The average exhalation temperature has been presumed to be at about 34°C for many decades. However, more recent studies reveal that the actual average exhalation temperature is closer to 35°C with a variant of about ± 2°C.
The exhalation temperature is influenced mainly by the ambient temperature, and a subject's breathing patterns like hypoventilation (holding breath) and hyperventilation (rapid breathing). The more common breathing maneuver is hyperventilation which will lower the exhalation temperature and consequently the breath alcohol concentration by as much as 20% (Jones, 1982c).
Yet, breath testing devices are calibrated to an alcohol concentration equivalent derived from a water/alcohol standard at 34°C.
In order to compensate for the breath temperature variance, a breath tester must be equipped with a low mass, fast responding temperature sensor near or within the mouthpiece to allow the breath tester to correct the breath test result to the (instrument calibrated) 34°C equivalent.
The exhaled breath temperature phenomenon has become the latest legal challenge topic.

J. Interfering Substance Susceptibility/Detection
First generation IR instruments were not specific for alcohol. These instruments observed IR absorption near the 3.4 µm wavelength range. Interfering substance susceptibility has been a common target for defense challenges due to the system's cross-sensitivity (false high readings) to acetone. Acetone can be produced endogenously by diabetics and starving individuals. Other potentially interfering substances are acetaldehyde, toluene, methyl alcohol and isopropyl alcohol.
Second generation 3.4 µm-range IR instruments utilize multiple optical filters to allow only specific IR energy wavelengths (IR channels) to reach the IR detector. Complimentary algorithms enable these instruments to discriminate between alcohol and other endogenous substances found in the human breath.
The latest advancements in IR spectrometry involves the absorption of IR energy at a wavelength of 9.5 µm. This eliminates the risk of interference by acetone and any volatile hydrocarbons found in human breath.
However, today's highest degree of ethanol specificity is achieved by combining a 9.5 µm IR system with an Electro-Chemical Cell sensor within the same instrument.

Dual Technology
It is a common forensic practice to validate an analytical process by analyzing one and the same specimen by two, independent analytical principals. Such chemical analysis is validated if both independent measurements are in reasonable agreement. The most advantageous combination of two independent analytical principals for breath-alcohol testing is IR spectrometry at 9.5 μm paired with an Electro Chemical Cell sensor. These instruments are able to produce two measurement readings from the same specimen.

K. Accuracy Verification With Every Breath Test
The assurance of the evidential breath tester's analytical accuracy, at the time a subject's breath is being tested, is of the utmost judiciary significance. Historically however, evidential breath analyzers were calibrated and certified usually once every year. And, during a one year period, a breath tester performs approximately 1,000 evidential breath tests (USA). If, during the process of running a yearly calibration/certification procedure, an instrument reveals that it's measuring accuracy isn't acceptable, the general course of action is to take this instrument out of service and invalidate all breath test results and convictions for the past 12 months back to the time when the last successful certification was performed. This is extremely detrimental for the integrity of a breath test program, the Scientific Director and the responsible Law-Enforcement departments.
Today, most experienced and advanced program administrators require an instrument-accuracy-verification at the time of every breath test. This strengthens every single DUI case and eliminates the risk of discreditation of the instrument and the program.
Accuracy verification tests are commonly performed with wet-bath simulators containing a water/ethanol standard or with a dry-gas ethanol standard containing a known concentration of certified ethanol/nitrogen mixture. These tests are automatically performed during the breath test sequence by the instrument without operator input. Furthermore, the instrument's microprocessor will disable the instrument immediately if the accuracy test result falls outside the regulated tolerance.

L. RFI (EMI) Detection
Some earlier breath testing devices were susceptible to Radio Frequency Interference (RFI) or Electromagnetic Interference (EMI). Today's evidential instruments offer RFI detection features. If the preset field strength limit is exceeded the breath test is aborted and must be repeated.

M. Instrumental Error Detection
Advanced microprocessor based instruments incorporate substantial internal error detection features. Any detected hardware or software error will halt and abort the test.

N. Data Collection
All advanced evidential breath test programs require data collection in conjunction with the breath test sequence. This includes specific data on the subject, the arresting officer, the operator, place of arrest, operator certification, IR absorption curve, etc. and all the test measurement data. All this information is printed by the instrument produced record and uploaded to a remote computer via modem or via an intranet system. The uploaded data is utilized to generate statistical reports, to focus DUI enforcement

personnel to strategic, geographic problem areas, to provide defense lawyers with documents (discovery law), to provide data to the license registration department, etc.

O. Ambient Barometric Pressure Detection
Recognition of the ambient barometric pressure at the time of the test allows automatic measurement correction of a dry-gas based accuracy verification test.

P. One Button Operation
One button operation has become a desired feature as it eliminates doubts in the operator's proficiency or any intervention with the breath test sequence. The instrument must follow a pre-programmed test routine specified by the local program administration and in accordance of local laws and guidelines.
Due to the sophistication of these breath-analytical elements and the complexity of all additionally required test features as mentioned above, only IR based instruments can integrate these functions while meeting the local regulatory requirements.

5. Breath-Test-Program Quality Assurance

Evidential breath test results and all parties involved with these tests are often subject of legal scrutiny. Aside from the integrity and sophistication of an advanced IR evidential breath-alcohol-analyzer, there are other important, complimentary program quality assurance aspects which must be considered and implemented. A written, comprehensive Quality Assurance Plan (QAP) must be established and accredited by the local government. This QAP should address at a minimum the following topics:

A. Rules and regulations describing every required step the law enforcement personnel must follow, from the observation of a DUI subject to the subject's conviction.
B. Administrative Rules describing operator's training curriculum, operator certification terms, instrument requirements, approval requirements, instrument maintenance requirements, evidential breath test sequence, data collection requirements, record keeping, etc.

6. Conclusion

Various human specimens can be considered for measuring a person's alcohol concentration level. All body fluids as well as expired breath are legitimate specimens for alcohol concentration measurements. However, the two most popular methodologies for medicolegal alcohol testing are blood analysis and breath analysis. Extensive scientific studies have validated the close correlation between simultaneous measurements of alcohol in blood and alcohol in breath.
For obvious reasons, breath-alcohol analysis has become the preferred evidential test method dating back to the 1950s: By comparison, the breath test is non-invasive, can be carried out and completed by the police staff without outside analysis, the entire test procedure is swift and the per-test-cost is only a fraction of blood analysis.

Roadside tests or so called screening tests are conducted with handheld, mainly EC based instruments. These instruments are portable, battery operated and provide quick test results. The main objective of these tests are for confirmation of probable cause for submission to an evidential test procedure.

Yet, breath testing as opposed to blood testing appears to be of greater interest for attack maneuvers by defense lawyers. The reason for this might be very subjective and simply due to the fact that there are significantly more breath tests performed compared to blood tests. It might also be that the defense sees easier prey in a policeman's breath-test proficiency compared to that of a University graduate operating a GC in a forensic laboratory.

In conclusion, Infrared technology has established itself as the preferred technology for breath-alcohol-analyzers in the US, Europe, Canada, Australia and many other countries. Incorporation of both IR and electro-chemical cell technologies further increases analytical specificity for ethanol and provides a second, technology-independent analysis. IR and EC combined is today's state-of-the-art method of evidential breath testing.