
Trouble-free sidestream gas analysis

Abstract

An effective technical solution to common problems conventionally associated with sidestream gas sampling and water removal sample-line sets, used with respiratory gas analysis devices, are described. Important clinically-related parameters such as waveform rise time, measurement latency, accuracy, and water and moisture removal are reviewed together with the risk assessment of key factors such as patient cross contamination. The features and benefits of a new gas sampling line, Nomoline™, which has the ability to remove water and moisture from the gas sample flow, are highlighted and contrasted with the performance of competitive products currently on the market. The Nomoline™ sample line is used exclusively with the PHASEIN ISA (Infrared Sidestream Analyzer) sidestream technologies for monitoring CO₂, N₂O, O₂, and the five anesthetic agents at low flow and high breath rates.

Introduction

The design of a sidestream sample line which could provide transparent and reliable performance for extended periods of time has been a long-standing challenge to developers of sidestream multigas analyzers. Ultimately, achieving as many performance characteristics as those which are routinely expected from mainstream multigas analyzers has been the goal.

To review, clinical gas analyzers are usually described as non-diverting (mainstream) or diverting (sidestream) instruments. Mainstream gas analyzers make use of a measurement head, normally positioned in the respiratory circuit close to the mouth or trachea of the patient. Such instruments analyze the gas composition directly in the respiratory gas stream whereas sidestream gas analyzers draw a minute gas flow (usually 50 - 250 ml/min) from the respiratory circuit through thin tubing, typically 6 feet long, to the instrument where the gas analyzer is located. Mainstream gas analyzers have the advantage that they provide an instant "true" representation of the gas mixture in the respiratory circuit while being far less susceptible to the influence of water vapor and patient excretions. However, since mainstream gas analyzers are passive measurement devices their use is preferred in department such as the ICU, where the patient may be intubated and the clinical requirement is for the highest fidelity respiratory gas analysis representation.

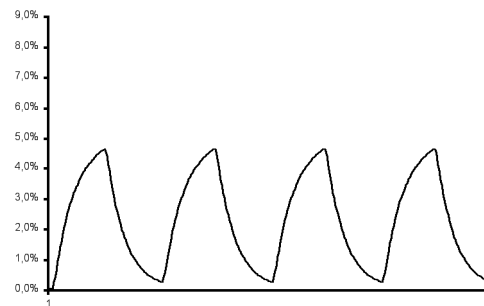
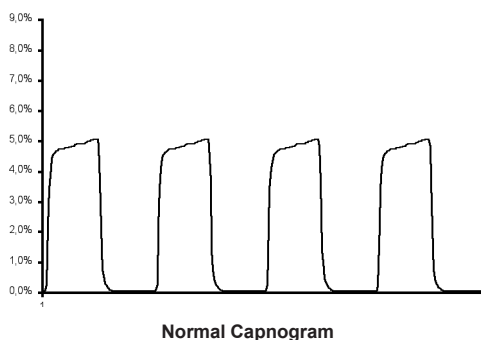
The fact that a sidestream instrument actively diverts a small gas sample from the respiratory circuit for analysis at an instrument located some distance from the patient makes it possible to use these devices on both intubated and non-intubated patients. By collecting the gas sample using an oral or a nasal cannula a sidestream instrument may be used to monitor both inspired and expired concen-

trations of carbon dioxide, oxygen and anesthetic gases, as well as the breathing activity (respiratory rate) of spontaneously breathing patients. Sidestream analyzers also have the advantage that they do not add weight to the patient connection site, and are therefore suitable for use with small infants and neonates. Sidestream devices can thus be used on a broader range of patient applications, which has made them more common in clinical practice than mainstream devices.

Technical limitations of sidestream gas analysis

As widespread as market adoption has been for both sidestream multigas analyzers in the OR and end-tidal CO₂ analyzers in the ICU and other areas of the hospital, this technology is not without its limitations. The laws of physics being what they are, there is an unavoidable small delay in the sidestream waveform representation due to time-of-flight of the sample flow to the measuring instrument, and it is more difficult to maintain waveform fidelity, as a function of a lower sample flow. Furthermore, the amount of water and other foreign particles present in the sample gas flow is proportional to the flow rate. It is therefore desirable to employ as low sample flow rate as possible. A low flow rate is also important when analyzing gas from patients having low tidal volumes such as infants and neonates so as to not divert a significant portion of the patient tidal volume into the sidestream instrument. The latest generation of gas analyzers minimizes this delay and waveform distortion while maintaining a low sample flow of 50 ml/min. Such capnometers can, despite the low flow rate, be used to monitor neonates and children having breath rates well above 80 breaths per minute.

If not properly dealt with in the design, waveform artifacts such as the failure of the capnogram to return to zero during inspiration¹, can be inappropriately interpreted as an adverse clinical indication. Also, distortion of the waveform, especially at higher breath rates, may similarly be clinically misinterpreted². In a properly designed sidestream gas analyzer, the sample line characteristics are in tune with the gas analyzer as a "system" to overcome these obstacles and attain satisfactory clinical performance.



Distorted Capnogram due to slow rise time

One of the more daunting challenges facing the design of a sidestream analyzer is the control and prevention of water vapor and patient secretions from reaching and damaging the measuring instrument or, at a minimum, influencing the accuracy of the measurements. This task is usually accomplished in the specific design of the sample line and/or with use of a water trap on the instrument side.

This challenge stems from the fact that the patient's expired respiratory gases are usually saturated with moisture at 37 °C. As the sample flow traverses through the sample line towards the gas analyzer, its temperature is cooled by the external environment. The water vapor within the sample flow therefore naturally condenses in the respiratory circuit as well as in the gas analyzer sample tubing. If allowed to reach the gas analyzer sample cell, the condensate may permanently damage the instrument or affect the measurement accuracy. In order to protect the instrument from the effects of condensed water, patient secretions and bacterial contamination, a sidestream gas analyzer must be fitted with a device that can block, remove, or separate these contaminants from the gas sample flow. Sidestream gas analyzer manufacturers deal with this crucial problem in various ways. GE Healthcare, Dräger Medical and Criticare Systems, for example, utilize a water trap in addition to Nafion® tubing, in the designs of their multigas analyzers. Nafion® removes gases based on their chemical affinity for sulfuric acid. Nafion is basically Teflon® with sulfuric (sulfonic) acid groups interspersed within it. Sulfuric acid has a very high affinity for water, so it absorbs water into the Nafion. Once absorbed into the wall of the Nafion tubing, the water migrates from one sulfonic group to another until it reaches the outside wall of the tubing, where it evaporates into the surrounding gas (air or other gas)³. Its effectiveness is affected by the humidity gradient between the inside and outside to the tubing (e.g., the outside relative humidity). Nafion does not remove any water in liquid form that may have accumulated within the sampling line. Furthermore, Nafion sampling lines must be handled with care due to the fragile nature of the material.

¹Pascucci, et al; (1989) Comparison of a Mainstream and Sidestream Capnometer in Infants; Critical Care Med; 17:560-562.

²ibid

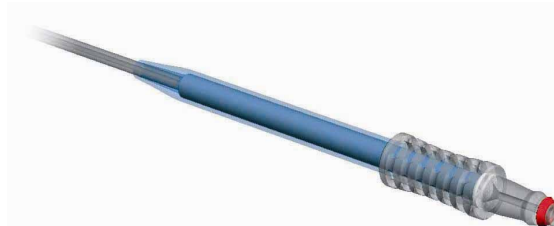
³Perma Pure, LLC; "Drying Technology: Microporous vs Nafion"; <http://www.permapure.com/tech-notes/key-concepts/drying-technology-microporous-vs-nafion/?ind=key-concepts>.

Oridion developed proprietary sample lines which can block water condensate from reaching the analyzer's sample cell with the use of a hydrophobic filter at the distal end of the filter lines. For high humidity applications, special filter lines with Nafion® segments are used. Respironics (now part of Philips) has also developed a proprietary filter line, which incorporates an integral sample cell as part of the sample line – a more expensive solution to the problem. A contaminated sample cell can be replaced by replacing the sample line. In both cases, Oridion and Respironics, the sample line design strategy incorporate methods for absorbing and blocking water condensate from reaching the analyzer itself. Respironics incorporate a combination of hydrophilic and hydrophobic filters to accumulate and block fluids from entering the sample cell, while Oridion utilizes a hydrophobic filter at distal end of the sample line to block fluids from entering the instrument. Both manufacturers incorporate Nafion® tubing in some versions of their sample lines in order to remove humidity and prevent its condensation in the line. In applications where copious amounts of patient fluids are present, or when high levels of humidity exists in the airway, sample lines of these types may have to be frequently replaced. In any case, both manufacturers recommend that the sample line replacement interval does not exceed 24 hours. Both Respironics and Oridion implicitly acknowledge that their fluid blocking technology is not infallible. A White Paper published by Oridion on their website⁴ acknowledges that their filter “substantially reduces the transmission of microdroplets of water vapor and microorganisms into the sensor chamber.” A comparison of their water handling capability⁵ of Oridion's Microstream® technology embedded in an OEM product, the Nellcor NPB-75, with Respironics' LoFlo™ embedded in GE's CapnoFlex LF monitor, observed that “During the trial, two NPB-75 monitors failed due to water and contaminants being drawn into the system.” Respironics also notes in one of their publications⁶ that “no filter is immune to eventual clogging and distortion of the capnogram”. The same publication describes an incremental improvement to the LoFlo filter design achieving “as much as a 2:1 improvement in life compared with the original LoFlo filter design.”

Phasein's Nomoline™ Technology

Nomoline is a completely new concept in gas sampling lines for gas analysis, combining the extended service cycle of a traditional water trap with the low flow characteristics and rapid response time of disposable water collecting sampling lines such as Respironics LoFlo and Oridion FilterLine. Nomoline's water handling performance is achieved by eliminating the liquid from the gas sample rather than collecting it in a reservoir or blocking it with an integrated filter.

The unique water removal function of the patented Nomoline sampling lines is based on the physical properties of



the Nomoline cover [2] as shown in Figure 1. The cover is molded using a specially formulated thermoplastic elastomer known as a Polyether Block Amide. These elastomers consists of a regular linear chain of rigid polyamide segments and flexible polyether segments having the general formula



where A represents the polyamide segment and B represent the polyether segment. The specific segments A and B and their blend ratio formulated for the Nomoline cover makes the NOMO Polymer transparent to moisture and water. Nomoline is therefore able to “sweat” water collected from the gas sample flow to the outer surface of the Nomoline cover and thus actively remove the water without user intervention.

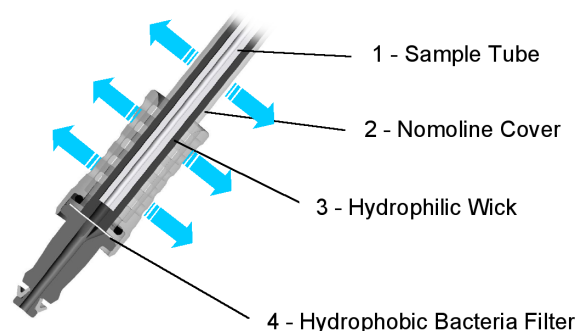


Figure 1

Nomoline is also fitted with a hydrophilic wick [3] with a volume of about 1.2 ml. The wick has the dual function of a buffer against sudden bursts of aspirated water and that of a water distributor, spreading the collected water over a sufficiently large area of water transparent material. This area is chosen to be large enough to continuously remove all the water that the gas analyzer may collect during normal operating conditions.

⁴ http://www.oridion.com/global/english/clinical_solutions/educational_resources/white_paper/liquid_secretion.html

⁵ McGhee, C. and Hammerschmith, M.; A comparison of the water handling capability of two sidestream capnographs; *Respiratory Care*, 50(11) p 1473, 2005.

⁶ Respironics White Paper; 21st Century CO2 Technology SM Side-stream Monitoring – The LoFlo™ System; © 2007 Respironics, Inc.

Nomoline is designed for applications where the gas sample may be returned back to the patient circuit. For these applications, analyzer cross contamination is an important consideration. To address this requirement, Nomoline is therefore fitted with a reliable 3 µm hydrophobic bacteria filter [4] that has a Bacteria Filtration Efficiency (BFE) exceeding 99.99996 %, as defined in MIL-M-36954C. The bacteria filter has a polyethylene backing making it mechanically rigid and a reliable water barrier should the sampling line be flooded with aspirated water beyond the capacity of the hydrophilic wick [3]. The gas measurement chamber, pump and other pneumatic components inside the gas analyzer are therefore effectively protected from water, secretions and microbes commonly found in the respiratory circuit.

The Nomoline rise time more than satisfies clinical requirements due to the uninterrupted flow design and the special connector used to engage Nomoline to the gas analyzer. This unique, positive “click” connector prevents the pitfalls common to the usual Luer fittings. To that point, it is not possible to engage the Nomoline connector in an “intermediate” position. Therefore, the risk of air leaks creating false low CO₂ values is thus minimized.

Another key feature of the Nomoline connector is an optical detector mechanism that senses if a sampling line is securely plugged in its socket. Furthermore, this detector mechanism incorporates a LED indicator that illuminates a green light (system OK, running), blinking red (occlusion), or blue (system ok, anesthetic agents present). That status indication is included in the data being passed to the host monitor. In addition, the Nomoline connector can rotate, thus minimizing the risk of kinks.

By comparison, a conical Luer connector always has a certain dead space between the male conical part and the female conical part. This dead space creates turbulence and distortion of the gas sample flow. The Nomoline connector does not suffer from this dead space resulting in the uninterrupted flow characteristic – a seamless, turbulence-free flow, where the Nomoline connector and socket are completely transparent to the sample flow dynamics. Luer connectors are very common on syringes and IV lines. It is thus quite possible to incorrectly fit a gas sample line to a patient fluid line or vice versa, creation a patient injuries risk, or damaging the gas analyzer. The proprietary Nomoline connector effectively removes these risks.

Because of the Nomoline’s uninterrupted flow design, it is therefore possible for the first time to monitor all the traditional respiratory gases including the five anesthetic agents at a low sample flow and high breath rates. Clinical trials on small babies undergoing general anesthesia (Sevoflurane) having breath rates above 60 bpm, were monitored with ISA multigas and Nomoline with very good results. Note that the GE Healthcare’s Datex bench, with its 200 ml sample flow rate, limits measurements to 60 bpm.

The competitive state of the art

The sample line technology for the major suppliers of OEM capnography and multigas monitoring technology vary greatly in terms of technical approaches, sophistication and performance. This section will discuss the sample line and water separation capabilities of Oridion’s FilterLine®, Philips (Respironics) LoFlo™, and conventional water traps such as are found in GE Healthcare’s (Datex) D-fend™, and Dräger Medical’s Vamos Plus Anesthetic gas monitor, based on the ILCA/ILCA2 OEM multigas analyzers.

Respironics LoFlo™

The LoFlo sampling lines uses a hydrophilic fibrous “sponge” [1], as shown in Figure 2, to collect up to about 210 µl of condensed or aspirated water from the patient circuit. At a sample flow of 50 ml/min this volume corresponds to about three hours of lifetime when used during standard high humidity conditions (37 °C patient circuit temperature at 100 %RH and 23 °C ambient temperature). When the sponge is filled with water a hydrophobic pellet filter [2] swells and blocks the liquid from entering the measurement chamber. The measurement chamber [3] is an integral part of the sampling line. There is however no filter that prevents other parts of the gas analyzer such as the pump from being contaminated by bacteria or other microbes present in the patient circuit, subjecting the entire analyzer to the prospect of cross contamination.

An extended lifetime version fitted with a section of dehumidifying tubing is available at a higher cost. This version of the LoFlo sampling lines works better in high moisture applications. The dehumidifying tubing can however not remove liquids from the gas sample stream - please refer to the Technical Evaluation section below for details.

Rise time figures for gas analyzers fitted with LoFlo sampling lines are quite good (200 ms) mainly due to the fact that the measurement chamber [3] is an integral part of the sampling line. The drawback with this design is however that zero calibrations must be performed manually by the operator. Another obvious drawback is the increased complexity and higher price of the product.

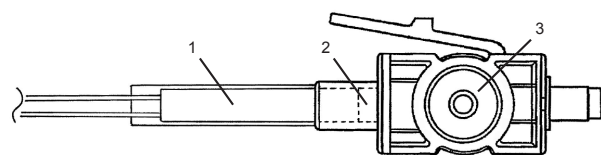


Figure 2

Oridion Filterline®

The FilterLine has a water reservoir fitted with hydrophobic fiber filter elements [1], as shown in Figure 3 that is able to collect up to about 160 µl of condensed or aspirated water from the patient circuit. At a sample flow of 50 ml/min this volume corresponds to about two hours and 20 minutes of lifetime when used during standard high humidity conditions. When the reservoir is filled with water the hydrophobic filters blocks the liquid from entering the measurement chamber. The fibers are however delicate and the automatic purge function of the Microstream® gas analyzers sometimes opens up small leaks in the fibers.

When this happens liquid is free to reach the sensitive measurement chamber of the gas analyzer thereby destroying the instrument. As previously noted in this document, McGhee and Hammerschmith, in their publication, point out the susceptibility of the FilterLine to this catastrophic failure mode.

FilterLine is also available in an extended lifetime version fitted with a section of dehumidifying tubing having similar properties as the LoFlo high humidity version - please refer to the Technical Evaluation section below for details.

Rise time figures for gas analyzers fitted with FilterLine sampling lines are good (250 ms), though not as good as Respironics' LoFlo. The main contributing factors to the slower rise time of the FilterLine sampling lines are dead space in the FilterLine conical fitting [2] and several fittings needed to connect the FilterLine receptacle on the instrument front panel to the Microstream gas analyzer. Oridion handles the slower rise time with a software acceleration algorithm enabled when the user sets the Microstream gas analyzer to neonatal mode. Such algorithms as described in a White Paper published by Perkin Elmer Optoelectronic on their website⁷ can improve measurements but "Because this type of correction, for adding gain to the moving parts of the gas samples, can add noise" to the capnogram.

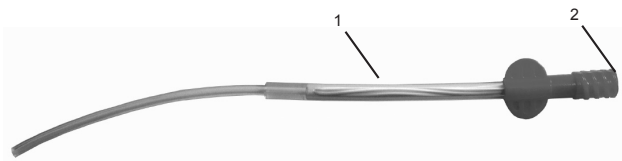


Figure 3

GE Healthcare D-Fend™

D-Fend represents a traditional water trap intended for a sampling flow of 200 ml/min. The trap is fitted with a hydrophobic bacteria filter acting as the liquid separating element.

The reservoir [1], as shown in Figure 4 a, is quite large with a volume of about 10 ml. At the nominal sample flow this volume corresponds to about 35h until the reservoir is full when the ambient temperature is 23 °C and the gas analyzer is sampling gas from a humid patient circuit at 37 °C.

The D-fend water trap, like other similar devices, requires that the reservoir [1] is located below the liquid separating element [2]. It is therefore not suited for mobile applications. Rise time figures of the D-fend water trap are high (500 ms) despite the relatively high sample flow. Breath-to-breath measurements above 60 bpm are therefore generally not possible.



Figure 4 a

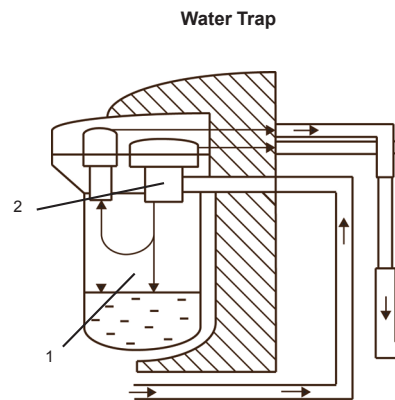


Figure 4 b

⁷ http://optoelectronics.perkinelmer.com/content/relatedlinks/articles/atl_gasanalysisignalprocessing.pdf

Sidestream Technology Comparison

	PHASEIN, ISA™	Philips, LOFLO®	Oridion, miniMediCO2
General			
Gas sensor	Multi channel (2 - 9 optical filters)	Dual channel (beam splitter)	Dual channel (Narrow band source)
Design	1 optical path, 1-2 reference filters	1 optical path, 1 reference filter	2 optical paths, 1 reference cell
CO2 [mmHg]	0 - 40: ± 1.5 mmHg + 2% of rdg 41 - 70: ± 1.5 mmHg + 2% of rdg 71 - 113: ± 1.5 mmHg + 2% of rdg 114 - 188: Unspecified	0 - 40: ± 2 mmHg 41 - 70: ± 5% of rdg 71 - 100: ± 8% of rdg 101 - 150: ± 10% of rdg	0 - 38: ± 2 mmHg 39 - 99: ± (5% of rdg + 0.08%/mmHg above 38 mmHg)
Respiratory Rate [bpm]	1 - 150: ± 1 bpm	2 - 150: ± 1 bpm	0 - 70: ± 1 bpm 71 - 120: ± 2 bpm 121 - 150: ± 3 bpm
CO2 Rise time	200 ms	200 ms	250 / 190 ms (Adult/neo)
O2 option available	Yes (paramagnetic)	No	No
N2O option available	Yes	No	No
Agent / Agent Id option	Yes / Yes	No / No	No / No
Analyzer			
Sampling flow	50 ± 10 ml/min	50 ± 10 ml/min	50 ± 7.5 ml/min
Sampling pump	BLDC Diaphragm	BLDC Diaphragm	BLDC Diaphragm
Pump lifetime	5 years of normal use	1 000 days	830 days (Old model: 291 days)
Power supply	5 V ± 10%, 1.4 - 1.6 W	5 V ± 5%, 1.3 - 2.0W	5 V ± 3%, 1.5 - 4.7 W
Interface	RS-232 or USB	RS-232	RS-232
Mechanical robustness	Repeated 6 feet drops	Repeated 6 feet drops	Not specified
Signal Processing			
Auto zero	Yes	No	Yes
Zero calibrations / 24 hrs	1	Manual	24
Initialization	< 10 sec	< 20 sec	40 to 180 s
Warm-up (to full spec)	10 sec	2 min	20 min
N2O compensation	Yes (manual)	Yes (manual)	No
O2 compensation	Yes (manual)	Yes (manual)	No
Pressure compensation	Yes (automatic)	Yes (manual)	Yes (automatic)
Temperature compensation	Yes (automatic)	Yes (manual)	No
Environmental			
Temperature [°C]	0 to 50 °C (32 to 122 °F)	0 to 40 °C (32 to 104 °F)	0 to 40 °C (32 to 104 °F)
Atmospheric pressure [kPa]	52.5 - 120 kPa	53.3 - 107 kPa	57.3 - 106 kPa
Altitude	Up to 5211 m / 17 096 feet	Up to 5094 m / 16 713 feet	Up to 4551 m / 14 930 feet
Samling lines			
Detection / indication	Yes / Yes	Yes / No	Yes / No
Water removal	Yes	No	No
Bacteria filter	Yes	No	Yes
Standard operating lifetime	2 weeks	12 hrs	6 hrs
Extended operating lifetime	2 weeks	120 hrs (Nafion versions)	72 hrs (Nafion versions)
Airway interface	Male Luer Lock		
(Infant & adult/pediatric)	Proprietary		
(Infant & adult/pediatric)	Proprietary		
(Infant & adult/pediatric)			
Cannulas	Third party	Nasal/Oral with/without O2	Nasal/Oral with/without O2
Others			
Span Calibrations required	No	No	Yes, annual
Mainstream models available	Yes	Yes	No

Figure 5, above, is a side-by-side comparison of the capabilities and specifications for the PHASEIN ISA multigas analyzer, the Philips (Respironics) LoFlo™ Sidestream CO₂ sensor, and Oridion's miniMediCO2 Microstream® module. Although the attributes of the three gas sensors are outside the scope of this document; the contributions of the sample line kits to the overall performance of the sensors are apparent. These contributions include a 200 ms rise time, detection and indication of the presence of a sampling line, water removal capability, utilization of a bacterial filter, and a useful operating life of two weeks.

The sample line specifications found in the table above are as published by their respective manufacturers. It is, however, not clear how Respironics and Oridion have arrived at these figures because the performance testing, described below, indicates that moisture and aspired water will yield lower lifetime figures in many clinical scenarios. The two-week lifetime specified for Nomoline is based on normal (high humidity) applications with low content of mucus and patient secretions. Please also note that Nomoline, LoFlo and FilterLine all are specified as Single Patient Use devices.

Performance testing

In order to substantiate the performance attributes of the three principal sidestream sampling line technologies being discussed in this document, characteristics pertaining to lifetime and measurement accuracy under various conditions were investigated according to the following table:

#	Analyzer	Sampling line
1	Microstream	FilterLine
2	Respironics LoFlo	LoFlo
3	PHASEIN ISA	Nomoline

Test configuration 'A'

In this test configuration, sample line lifetime as a function of patient circuit humidity was investigated using the following set up:

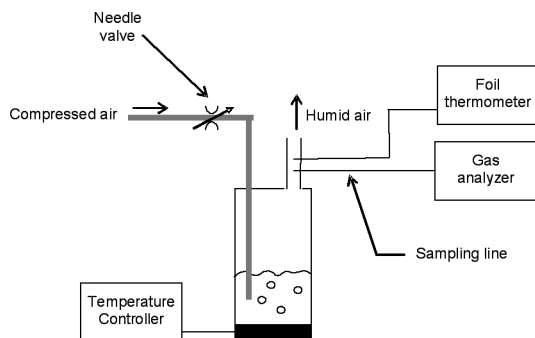


Figure 6

Compressed air at 3 liters/minute was fed through a container with heated water. The temperature of the water was varied, using the temperature controller, and the resulting humid air in the exhaust port of the container was fed through the sampling line under test to the gas analyzer. The temperature of the gas in the exhaust port of the container was measured using a foil thermometer and partial pressure of the water vapor was calculated assuming that the exhaust air was fully saturated with humidity at the measured temperature. The time until the gas analyzer reported "sampling line clogged" was recorded. The results are shown in the following graph:

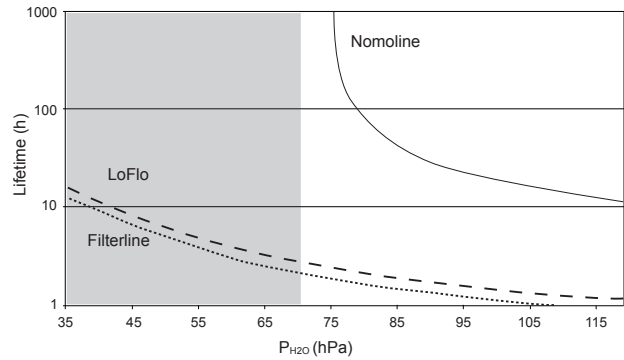


Figure 7

The shaded area in figure 7 indicates a normal clinical P_{H_2O} range. The lifetime limiting factor for Nomoline is thus not the moisture content of the sampled gas during normal clinical conditions.

Test configuration 'B'

In this test, sample line lifetime as a function of aspired water from the patient circuit was investigated using the following test set up:

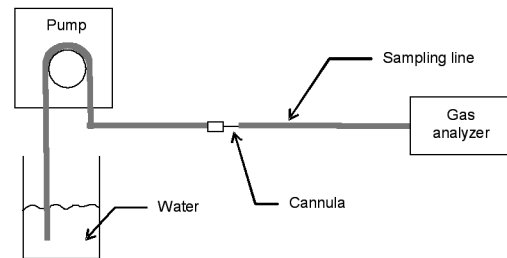


Figure 8

Water was fed from a container to a small cannula using a micro flow peristaltic pump. The gas analyzer was set up to sample ambient air and water from the cannula. The time until the gas analyzer reported "sampling line clogged" was recorded. The results are shown in the following graph:

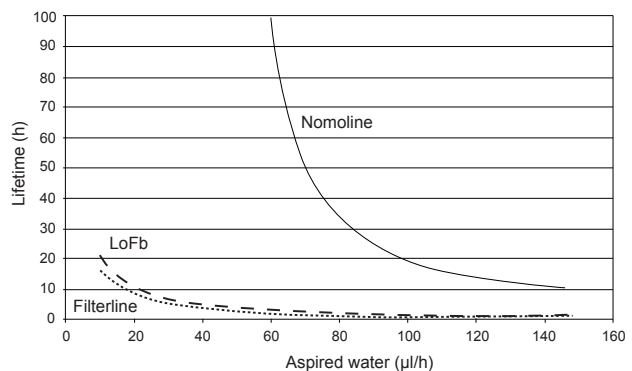


Figure 9

Test configuration 'C'

ETCO₂ accuracy for the three different sampling lines at various breath rates was investigated using the following test setup as described in the international standard ISO 21647, clause 51.102:

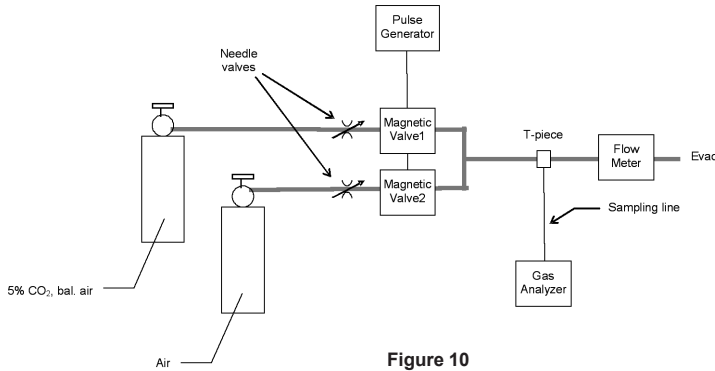


Figure 10

Gas flow through magnetic valves 1 and 2 was set to 5 liters/min by means of the two needle valves. The gas mixture through valve 1 was 5% CO₂ with a balance of air, and through valve 2, air. The pulse generator was set up to generate simulated breaths at a rate of 10 breaths per minute having an inspired to expired ratio of 50%, e.g. valve 1 was open for 3 seconds, followed by valve 2 opened for 3 seconds. The time of the expired phase was subsequently shortened to simulate short breaths corresponding to higher breath rates. The results are shown in the following graph:

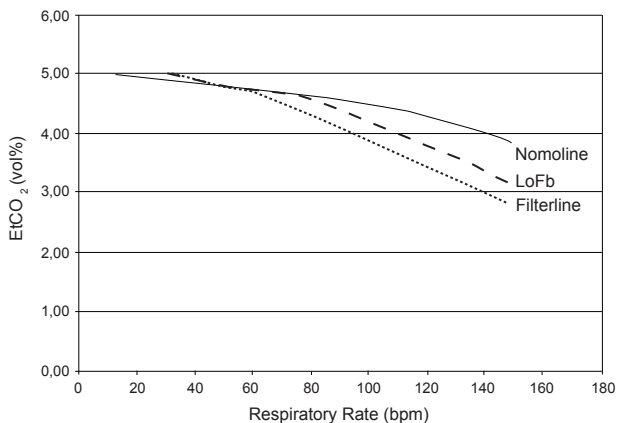


Figure 11

Analysis

The above presented tests results scientifically and unambiguously demonstrate that the Nomoline sample line's performance can be expected to exceed that of its leading competitors in three key areas: continuous, reliable, performance when used in high humidity breathing circuits; provide extended service, minimizing the need for frequent sample line replacements, even in the presence of significant quantities of aspirated water or patient secretions; and provide more accurate performance at higher breath rates, a tangible advantage when used in neonatal applications.

To review the above results in detail, Figure 7 demonstrates the water removal properties of the NOMO polymer cover as water vapor escapes from the sample line and is not trapped within to condense as it would with either the LoFlo or the Microstream sample lines. Under extreme humidity conditions, approaching rain-out, the Nomoline provides a minimum of ten hours of water removal protection.

A second line of defense takes over when sustained high-humidity conditions occur, especially during a cool ambient environment, or when aspirated water is "sucked" into the sample line. The backup defense mechanism is the hydrophobic filter which blocks the water from entering the sensor if and when the hydrophilic filter becomes fully saturated. In Figure 9, it can be seen that even at the rate 140 µl/hour of water being injected into the sample lines, the Nomoline still provides 10 hours of protection, where the LoFlo's and Microstream's protection diminish to well less than an hour.

The asymptotic shape of the Nomoline curve, on both Figure 7 and 8, shows that as long as the water input into the Nomoline, either in vapor or liquid state, does not exceed its ability to "sweat out" that volume of water gas can continue to flow without interruption. These curves further show that as the volume of water exceeds the Nomoline's water removal ability its performance degradation is graceful for significant periods of time beyond that of its competitors.

Figure 11, representing the results of the breath-to-breath accuracy test, illustrates that the PHASEIN ISA sidestream analyzer with the Nomoline sample line more accurately tracks the incoming reference CO₂ gas mixture at rates greater than 80 breaths/minute up to the maximum specified rate of 150 breaths/minute without the use of any compensating software algorithms.

Conclusion

In his website, <http://www.capnography.com>, Dr. Bhavani Shankar Kodali articulates his vision of an "ideal capnograph". Near-mainstream performance in a sidestream unit, and prevention of secretions being drawn into the capnographs are two of the points he highlights in this vision. The PHASEIN Nomoline, as part of the ISA sidestream multigas analyzer, advances CO₂ and multigas sidestream monitoring technology closer to achieving this vision.

The Nomoline's three protective elements, the connector and socket design, all work in unison to remove water from the sample line, and create an *uninterrupted flow* dynamic, so as to provide extended and accurate performance in demanding clinical applications. The Nomoline's useful service life is akin to that of a high-capacity water trap, but with the advantages of low sample gas flow, crisp rise time, accurate waveform representation, and freedom from bacterial cross contamination.