

21st Century CO₂ Technology Sidestream Monitoring - The LoFlo System

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ABSTRACT

The features and benefits of the LoFlo Sidestream System are detailed and contrasted with existing systems and sampling sets.

INTRODUCTION

Non-dispersive infrared (NDIR) gas analyzers are widely used in medical applications and fall into two categories: (1) “diverting” or “sidestream”; and (2) “non-diverting” or “mainstream” (ISO 21647, 2004). A mainstream gas analyzer includes a sample cell positioned in the breathing circuit through which a patient’s inspiratory and expiratory gases flow. A sidestream gas analyzer samples gases from a sampling port in an adapter placed in a breathing circuit or from a nasal or nasal/oral cannula. The gas then passes through a sampling tube to the sample cell, where the gas components are measured. Typically, the sampling port is located on the patient side of an in-line filter:

Conventional sidestream capnographic monitoring requires that careful attention be paid to the physical setup, both external and internal to the monitor, and as a result, additional care must be taken in interpreting the capnographic waveform. Condensation from a humidified sample gas, in combination with patient secretions, can block and contaminate the sampling tube, which may necessitate frequent replacement. To help protect the sample cell from condensate and extend the life of the accessory, a portion of the sampling tube is often made permeable to water vapor by using dehumidifying tubing such as Nafion® brand tubing, and a water trap/filter is positioned at some point along the length of the sampling tube. The effectiveness of filter designs varies between manufacturers, but no filter is immune to eventual clogging and distortion of the capnographic waveform, particularly if preventive maintenance is inadequate. While more recent sidestream analyzer designs have sampling ports in the center of the adapter rather than at a wall and, therefore, are less likely to aspirate secretions, they are still susceptible to the problems outlined. (For further details on mainstream vs. sidestream gas sensors, refer to Respirationics whitepaper, *Mainstream or Sidestream Capnography*). Additionally, conventional sidestream systems are often integrated with multi-parameters in such a way

as to limit the ability to choose the most appropriate gas monitoring modality (i.e. sidestream or mainstream) for the clinical situation.

Given these problems with conventional sidestream capnography, it is desirable to provide a sidestream gas analyzer that (a) is more robust with respect to accumulation of condensate and patient secretions, (b) facilitates an easy determination of problems and corrective actions at the point of care should any of the problems noted above occur with the sampling tube and/or the sample cell, and (c) allows for flexibility with respect to mode of gas monitoring.

THE LOFLO APPROACH

To address the problems noted, the LoFlo Sidestream Gas Monitoring System includes a removable and disposable sample cell, which effectively obviates the need for preventive maintenance of the sample cell. (For further details, refer to Respirationics white paper, *Sidestream Gas Monitoring with a Detachable Sample Cell - The LoFlo System*).



Figure 1 - LoFlo C5 Module

THE LOFLO C3

The CAPNOSTAT 3-based LoFlo C3 platform permits system integration with legacy mainstream-only-monitors. This LoFlo technology may be incorporated into a monitoring system as an external sidestream module or a sidestream module to be included within a multi-parameter system. To make this novel technology available to the existing installed base of multi-parameter monitors, an approach has been developed that enables external sidestream gas sensor modules to be interfaced with existing systems originally designed to interface to the CAPNOSTAT 3 mainstream CO₂ sensors. To accomplish this, the sidestream module must emulate the mainstream sensor's physical, signal/control and power interfaces.

LOFLO C5

The Respironics LoFlo C5 sidestream sensor adapts the measurement technology in the mainstream CAPNOSTAT 5 platform to a sidestream platform. This platform offers several improvements over the previous C3 platform: reduced size and increased integration, sample cell interchangeability and improved temperature compensation.

Reduced size and increased integration – The LoFlo C5 platform using the technology developed for the CAPNOSTAT 5 mainstream sensor integrates into a single package (about the size of a computer mouse) (Figure 1) all of the front-end electronics, signal processing and optical components needed for a capnometer. By integrating all of the signal processing and control functions into the sidestream module and assembling it in a compact way using a novel manifold structure, a simple to use, compact sidestream solution can be achieved (Figure 2). Like the CAPNOSTAT 5 mainstream sensor; this provides a complete CO₂ sensor that requires only a power source and serial connection.

Interchangeability – Gas monitor selection, whether diverting (sidestream) or non-diverting (mainstream), is often determined by what is available to the clinician and not what is optimal for the application. The LoFlo and CAPNOSTAT sensors provide the clinician with the ability to easily choose between a compact mainstream and/or compact sidestream solution.

Improved Temperature Compensation – To achieve even greater robustness, an on-board temperature sensor is in thermal contact with the manifold, thereby permitting the gas temperature to be determined.

In addition to the improvements noted above, the LoFlo engine provides a complete, compact and robust sidestream monitor in a package measuring only 4.5 cm (W) by 7.5 cm (L) by < 3 cm (H).

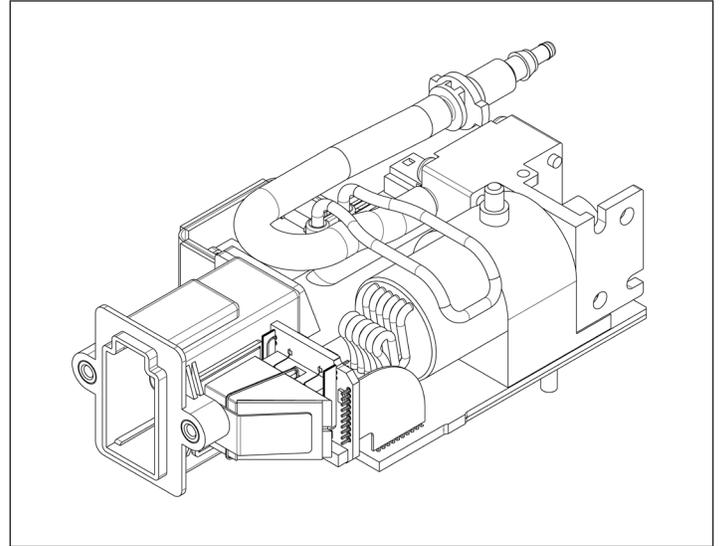


Figure 2 - Perspective view of the LoFlo engine (with cover removed)

SIDESTREAM SAMPLING SETS

The sampling set consists of a sample cell, filter, sampling tubing, an interface to the patient or the breathing circuit, and in some kits dehumidification tubing, all integrated into each LoFlo accessory. The sample cell portion of the sampling set is designed to permit easy connection and disconnection. These sample sets may include various additional components, such as filters, dehumidification tubing, oxygen delivery tubing, and a connector. The sample sets may be interfaced to the patient's airway by a nasal cannula, airway adapter or a low deadspace airway adapter. A complete range of sampling sets for intubated and non-intubated patients is available for the LoFlo platforms.

THE FILTER

The filter portion of the sampling set must not degrade the sample and must provide maximum water handling capabilities. The design of the LoFlo sampling set filter has successfully achieved these goals.

Clinical Study – A poster presentation at the 2005 AARC meeting (McGhee and Hammerschmith, 2005) compared the water handling capabilities of the Respironics sidestream sampling accessories provided for use with the GE (LoFlo) Capnoflex (mated to GE's Dash® monitor) to the sidestream sampling accessories provided for use with the NPB 75 (Nelcor,

Boulder, CO) Microstream (sidestream) CO₂ hand-held pulse oximeter/capnograph. It was noted that the motivation for the study was previous water handling problems of the NPB-75 system which resulted in these monitors being rendered non-operational by aspirated condensate, and the associated costly repairs.

The two capnography products were run simultaneously on eight intubated critically-ill adult ICU patients who were expected to be mechanically ventilated for at least twenty-four hours. Two adult airway adapters (one for each monitor) were connected in tandem between the closed suction system adapter and the ventilator circuit wye with the order of the adapters chosen at random. The two capnographs were observed periodically over the duration of the evaluation, and observations were recorded manually on data sheets. Patient age and diagnosis as well as the number of “accessories” used by each monitor were recorded.

The studies lasted between 8 and 27.75 hours. On average, NPB MicroCap® Filter Line H accessories (disposables) were consumed at a rate of 3 for every CapnoFlex accessory (also disposable), due to build up of condensed water vapor which either blocked the filter or was aspirated into the monitor. During these tests, two Nellcor monitors were put out of service due to water getting inside the infra-red bench of the unit, requiring service. During the course of this comparison, the original GE CapnoFlex accessories continued to function without problems.

Table 1 – Comparison of number of sampling sets used during monitoring period for 8 subjects (from McGhee and Hammerschmith, 2005).

	Time Monitored	# of Microcap FilterLine H	# of CapnoFlex LoFlo
1	24h	3	1
2	24h	4	1
3	24h	3	1
4	24h	3	1
5	27.75h	4	1
6	18.25h	3	1
7	24h	3	1
8	8h	1	1
	TOTAL	24	8

Testing was performed with accessories using the original LoFlo filter design.

The authors conclude from this testing that these Nellcor NPB-75 monitors are susceptible to problems with accumulation of condensed water vapor which results in increased cost of disposables during long term monitoring. They also note these problems can lead to increased repair costs, since the NPB disposable accessories do not appear to protect the monitor from fluid build-up.

Improved Filter Design – In an effort to further improve water handling capabilities, Respironics sampling sets use a hydrophilic fibrous element followed by a hydrophobic plug. The hydrophilic filter consists of a network of fibers that absorb the water vapor/droplets. This network of fibers has a significant volume into which it can expand and capture a significant quantity of liquid. The hydrophobic plug follows the hydrophilic filter and serves to block the passage of any water vapor/droplets not captured by the filter.

To assess the performance of this filter design, laboratory and clinical testing was performed. The laboratory tests included life tests under humidified conditions of the sampling sets, with and without Nafion tubing. A ventilator with a humidifier was interfaced to LoFlo sampling sets for use with a humidified breathing circuit. The airway adapters of each sampling set were interfaced to a test lung maintained at a constant temperature. The airway humidity was maintained at 100% and confirmed with a hygrometer. The temperature was confirmed by a thermocouple in the airway. These experiments under humid conditions in conjunction with clinical testing have confirmed the 12-hour and 120-hour minimum life of the sampling sets without and with Nafion tubing, respectively.

CONCLUSIONS

The LoFlo system offers a robust, compact platform that is resistant to water and uses sampling sets that provide exceptional performance and water handling capabilities. Used in conjunction with the CAPNOSTAT 5 mainstream sensor, the LoFlo sensor provides the user with the ability to select the gas monitoring modality (mainstream or sidestream) that is most appropriate for the clinical situation.

REFERENCE

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