# New Generation Non-Soda Lime Absorbents:

## Factors Affecting Patient Safety During Inhalational Anaesthesia; *in vitro* evaluation of AMSORB® PLUS and LoFloSorb®

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***Short Summary***

*AMSORB PLUS and LoFloSorb carbon dioxide ($CO_2$) absorbents for anaesthesia varied in respect to carbon monoxide (CO) production, anaesthetic agent adsorption and $CO_2$ absorption capacity in an anaesthesia simulation model. Fresh, partially-desiccated and fresh-desiccated LoFloSorb produced small amounts of CO but markedly adsorbed or eliminated anaesthetic vapour in the order isoflurane → sevoflurane → desflurane with significant adsorption occurring during simultaneous absorption of $CO_2$ in the first 20 minutes of simulation. Fresh-desiccated LoFloSorb adsorbed 57% of 4% sevoflurane for 74 minutes and 48% of 4% isoflurane for 62 minutes, whereas fresh-desiccated AMSORB PLUS adsorbed 19% for 24 minutes and 3% for 5 minutes respectively. Fresh LoFloSorb caused a delay in reaching 90% (3.6%) of 4% sevoflurane for 37 minutes and took 38 minutes to reach 90% (1.8%) of 2% isoflurane whereas AMSORB PLUS took 8 minutes and 6 minutes respectively. LoFloSorb appeared to possess greater adsorption capability with desflurane, when partially-desiccated, compared to when fresh-desiccated.*

*Fresh-desiccated and partially-desiccated LoFloSorb absorbed 45% and 90% less $CO_2$ respectively than fresh and partially-desiccated AMSORB PLUS. There were also differences in respect to the rate at which both absorbents became desiccated by oxygen, with LoFloSorb only marginally more resistant to desiccation compared to AMSORB PLUS. Suitability of LoFloSorb for inhalational anaesthesia should be evaluated by users in respect of their requirements for patient safety and $CO_2$ absorption capacity. Further research should consider what happens to anaesthetic vapour that has become adsorbed and whether potential exists for revapourisation of this vapour at some further point, perhaps triggered by an increase in absorbent temperature caused by the exothermic reaction of absorption of $CO_2$ and whether such unintentional anaesthetic vapourisation poses risk to patients or creates erroneous patient monitoring data.*

### Abstract

Desiccated soda lime degrades halogenated anaesthetics to carbon monoxide (CO), formaldehyde, methanol, dimethoxymethane and vinyl ethers of which Compound A production, resulting from interaction with sevoflurane, has been described[1]. Some desiccated absorbents may concurrently adsorb anaesthetic vapour, in phenomena first described by Grodin[2]. All commercially available medical $CO_2$ absorbents use calcium hydroxide lime ($Ca(OH)_2$) as the neutralising base for carbon dioxide ($CO_2$) produced during anaesthesia respiration. Absorbents differ in minor ingredients, included as absorption catalysts and hardeners, of which sodium hydroxide (NaOH) is common. These ingredients are known to compromise the proper functioning of the absorbent, under specific conditions and with specific types of absorbent. Water is an essential ingredient, common to all absorbents, and is necessary for efficient $CO_2$ absorption and, in the case of some absorbents, for avoiding

[1] See general reading list in Appendix A
[2] Grodin WK et al. Soda lime adsorption of isoflurane and enflurane. Anesthesiology 1985; vol. 62(1); pp60-64

adsorption and degradation of anaesthetic vapour. In 2005, APSF (Anesthesia Patient Safety Foundation) published a consensus statement[3] advising anaesthesia providers against use of absorbents that significantly degrade anaesthetic vapour.

Absorbent hydration levels are known to affect the extent of vapour degradation, with complete desiccation causing most degradation. Content of NaOH in conventional soda lime is known to additionally affect degradation, as does the halogenated agent used, with most degradation (in respect of CO) in the order desflurane → enflurane → isoflurane → sevoflurane → halothane. Absorbent desiccation is caused by inadvertent gas flow through the absorber canister during periods of non-use or, intentionally by evaporation of water during clinical absorption of $CO_2$, as part of an exothermic reaction during conversion of $Ca(OH)_2$ to calcium carbonate ($CaCO_3$), aided by the associated drying effect of fresh gas flow. Desiccated absorbents, in general, are known to adsorb or *eliminate* halogenated anaesthetics, (to varying degrees in respect of some absorbents), with simultaneous degradation of anaesthetic vapour. Absorbents containing molecular sieve zeolites and silica are reported as having significant potential in this regard[4].

Desiccation of fresh (unused) absorbent has been shown to result from inadvertent gas flow but no data exists on the extent of desiccation from $CO_2$ absorption alone. Neither does data exist on the ability of clinically exhausted and desiccated absorbent to degrade and adsorb halogenated anaesthetics; as previous studies tested the characteristics of fresh-desiccated but not exhausted absorbents. The role of the insoluble precipitate $CaCO_3$, a by-product of exhaustion of the absorbent, is of particular interest to the study design with respect to anaesthetic vapour adsorption and degradation. Current advice from manufacturers of some absorbents is that avoiding inadvertent desiccation by gas flow during periods of non-use will render the absorbent otherwise safe to use. This advice may be somewhat misguided, as data has not previously been available to confirm the level of desiccation from clinical exhaustion of the absorbent.

New generation non-soda lime absorbents (NSL), AMSORB® PLUS (Armstrong Medical Limited, Coleraine, Northern Ireland) and LoFloSorb (Intersurgical Limited, Wokingham, UK) claim to eliminate or reduce, respectively, degradation of vapourous anaesthetics, purportedly making them safer for use than absorbents containing NaOH or other strong alkali base.

The present study examines NSL absorbents' ability to produce CO and adsorb *anaesthetic vapour, in their fresh state, partially-desiccated/exhausted state (hereinafter referred to as partially-desiccated state) when in contact with 2% and 4% isoflurane, 4% and 8*% sevoflurane and 12% and 16% desflurane and in their *fresh-desiccated state.* 'Fresh state' refers to when the absorbent is unused and has adequate moisture content, in line with random samples of fresh absorbent recovered from hospitals; partially-desiccated state refers to used absorbent, exhausted to 50% of its original viable $Ca(OH)_2$ content and desiccated from absorption of $CO_2$ to breakthrough of 0.5% $FiCO_2$ and then further conditioned to bring the moisture content to 3.8% ±0.5 $H_2O$ by flow of oxygen (note that this further conditioning required a reduction in the hydration level with all absorbents); 'fresh-desiccated state' refers to unused absorbent desiccated by gas flow.

Critical elements such as anaesthetic vapour adsorption and CO production are examined, along with $CO_2$ absorption capacity, rate of dehydration and permanency of colour change relative to absorbent hydration. Medisorb absorbent (GE Healthcare, Helsinki, Finland) is used as the control in tests. Medisorb is a conventional soda lime, widely reported as having significant capability of producing CO when desiccated and in contact with vapourous anaesthetics[5].

*Fig. 1. Fresh AMSORB PLUS (white coloured) and desiccated AMSORB PLUS (violet coloured)*

[3] Olympio MA et al. Carbon Dioxide Absorbent Desiccation Safety Conference Convened by APSF. APSF Newsletter Summer 2005, vol. 20, No. 2, pp. 25, 27-29

[4] Knolle E et al. Small Carbon Monoxide Formation in Absorbents Does Not Correlate with Small Carbon Dioxide Absorption. Anesthesia & Analgesia 2002; vol. 95; pp650-655

[5] Keijzer C *et al*. Carbon monoxide production from desflurane and six types of carbon dioxide absorbents in a patient model. Acta Anaesthesiologica Scandinavica 2005; vol. 49; pp. 815-818

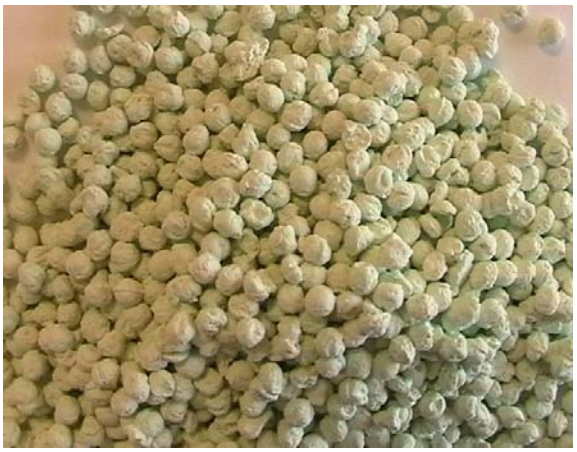


*Fig. 2. Fresh LoFloSorb (green coloured)*

## Full Summary

### CO production

Test results show that LoFloSorb produces CO *in vitro* when in contact with vapourous anaesthetics, in the order sevoflurane → isoflurane → desflurane for fresh absorbent and in the order isoflurane → sevoflurane → desflurane for fresh-desiccated absorbent (see tables 1-3). Peak CO levels found with fresh LoFloSorb, across all three anaesthetic agents, reached 7ppm±4 with isoflurane at 4% - less with the other agents. Peak CO levels found with fresh-desiccated LoFloSorb across all three anaesthetic agents, were 48ppm±18 with isoflurane. Fresh or fresh-desiccated AMSORB PLUS did not produce CO beyond background interference (1ppm) in a small number of tests. It should be noted that, when desiccated, neither absorbent has the required capability to absorb clinical loadings of $CO_2$. This data supports the earlier findings of Knolle.

Table 1.

| **Sevoflurane 8%** | **Peak CO** | **Median CO** |
|---|---|---|
| AMSORB PLUS, fresh | 0 | 0 |
| LoFloSorb, fresh | 5 | 2 |
| Medisorb, fresh | 10 | 6 |
| AMSORB PLUS, fresh desiccated | 1 | <1 |
| LoFloSorb, fresh desiccated | 40 | 24 |
| Medisorb, fresh desiccated | 410 | 287 |

Table 2.

| **Isoflurane 4%** | **Peak CO** | **Median CO** |
|---|---|---|
| AMSORB PLUS, fresh | 0 | 0 |
| LoFloSorb, fresh | 7 | 3 |
| Medisorb, fresh | 25 | 8 |
| AMSORB PLUS, fresh desiccated | 0 | 0 |
| LoFloSorb, fresh desiccated | 48 | 28 |
| Medisorb, fresh desiccated | 810 | 537 |

Table 3.

| **Desflurane 16%** | **Peak CO** | **Median CO** |
|---|---|---|
| AMSORB PLUS, fresh | 0 | 0 |
| LoFloSorb, fresh | 6 | 1 |
| Medisorb, fresh | 45 | 23 |
| AMSORB PLUS, fresh desiccated | 0 | 0 |
| LoFloSorb, fresh desiccated | 35 | 17 |
| Medisorb, fresh desiccated | 1,010 | 693 |

Data for peak CO production from partially-desiccated absorbent did not prove statistically significant and levels stayed below 55ppm or 0.0055% volume.

### Adsorption of Anaesthetic Vapour

Adsorption of anaesthetic vapour was pronounced with fresh, fresh-desiccated and partially-desiccated LoFloSorb and less so with fresh and fresh-desiccated and partially-desiccated Medisorb and AMSORB PLUS (see tables 4-6). Time to equilibrium to 90% of the vapouriser setting was consistently greatest with fresh, fresh-desiccated and partially-desiccated LoFloSorb, with all three anaesthetic agents and least with fresh, fresh-desiccated and partially-desiccated AMSORB PLUS. In all absorbents, the time to equilibrium and the percentage adsorption of the vapour varied with agent concentration and hydration level of the absorbent. Adsorption by fresh LoFloSorb appeared greatest with sevoflurane and isoflurane and less with desflurane. The greatest level of adsorption appeared with fresh-desiccated LoFloSorb and isoflurane at 2% and 4% in which 48% of the delivered anaesthetic vapour was eliminated during the first 40 minutes of the study, with equilibrium to 90% of the vapouriser being achieved at 68 minutes and 62 minutes respectively. Comparative data for fresh LoFloSorb was 38 minutes and 21 minutes for 2% and 4% isoflurane, respectively. For partially-desiccated LoFloSorb, equilibrium was not reached until 29 minutes and 48 minutes for 2% and 4% isoflurane, respectively, suggesting that LoFloSorb, in clinical use, has significant capacity to adsorb anaesthetic vapour, whilst simultaneously absorbing $CO_2$. The lowest level of agent adsorption by a fresh-desiccated absorbent was recorded with AMSORB PLUS in which equilibrium was reached after just 5 minutes at 4% isoflurane and 6 minutes at 2% isoflurane, suggesting that AMSORB PLUS has very limited capability to adsorb anaesthetic vapour.

Table 4.

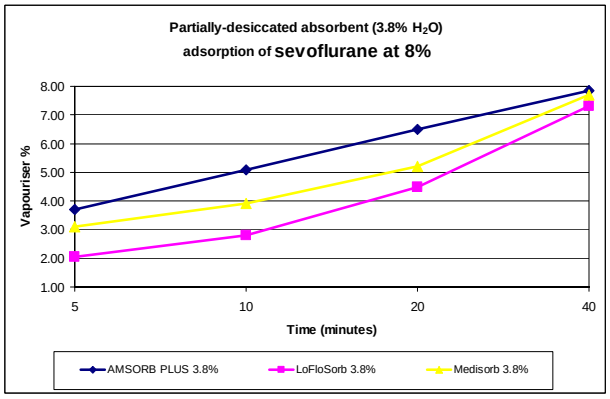
| Sevoflurane 8% | Adsorption: Total time to equilibrium (min) to 90% of vapouriser setting | Adsorption: Total vapour volume loss to 40 min (%) |
|---|---|---|
| AMSORB PLUS, fresh | 8 | |
| LoFloSorb, fresh | 28 | |
| Medisorb, fresh | 14 | |
| AMSORB PLUS, partially-desiccated | 23 | |
| LoFloSorb, partially-desiccated | 37 | |
| Medisorb, partially-desiccated | 31 | |
| AMSORB PLUS, fresh desiccated | 22 | 19 |
| LoFloSorb, fresh desiccated | 80 | 39 |
| Medisorb, fresh desiccated | 41 | 29 |

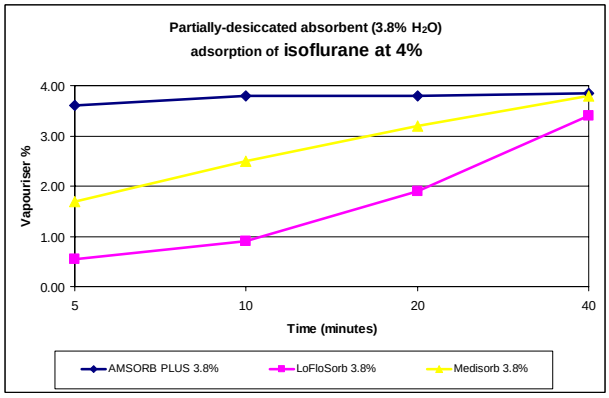
Table 5.

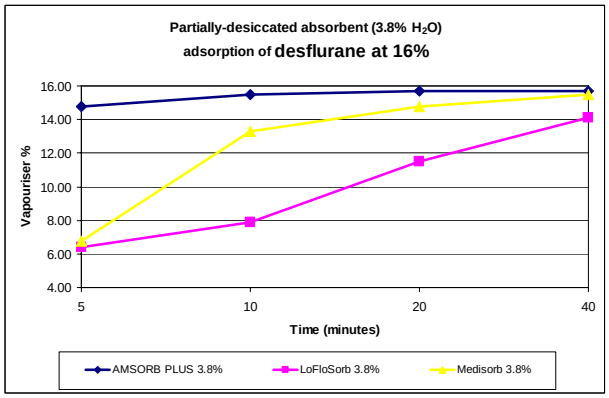
| Isoflurane 4% | Adsorption: Total time to equilibrium (min) to 90% of vapouriser setting | Adsorption: Total vapour volume loss to 40 min (%) |
|---|---|---|
| AMSORB PLUS, fresh | 6 | |
| LoFloSorb, fresh | 21 | |
| Medisorb, fresh | 20 | |
| AMSORB PLUS, partially-desiccated | 5 | |
| LoFloSorb, partially-desiccated | 48 | |
| Medisorb, partially-desiccated | 31 | |
| AMSORB PLUS, fresh desiccated | 5 | 3 |
| LoFloSorb, fresh desiccated | 62 | 48 |
| Medisorb, fresh desiccated | 32 | 19 |

Table 6.

| Desflurane 16% | Adsorption: Total time to equilibrium (min) to 90% of vapouriser setting | Adsorption: Total vapour volume loss to 40 min (%) |
|---|---|---|
| AMSORB PLUS, fresh | 5 | |
| LoFloSorb, fresh | 19 | |
| Medisorb, fresh | 17 | |
| AMSORB PLUS, partially-desiccated | 3 | |
| LoFloSorb, partially-desiccated | 43 | |
| Medisorb, partially-desiccated | 13 | |
| AMSORB PLUS, fresh desiccated | 6 | 5 |
| LoFloSorb, fresh desiccated | 26 | 23 |
| Medisorb, fresh desiccated | 23 | 15 |




## $CO_2$ Absorption Capacity

$CO_2$ absorption capacity in fresh or partially-desiccated absorbent was greatest with AMSORB PLUS and least with LoFloSorb (see tables 7-9). $CO_2$ absorption capacity was not influenced by choice of anaesthetic agent but was affected by absorbent hydration levels. Fresh AMSORB PLUS, on average, has 45% more absorption capacity than LoFloSorb, presumably due to the absence of any absorption catalyst within the LoFloSorb formulation. Fresh AMSORB PLUS, on average, has 27% more absorption capacity than Medisorb. More striking results were found for partially-desiccated absorbents, where AMSORB PLUS had almost 10 times more absorption capacity than LoFloSorb, when $CO_2$ absorption resumed. $CO_2$ absorption activity in fresh-desiccated absorbent was greatest with Medisorb and least with LoFloSorb and AMSORB PLUS. Of the fresh-desiccated absorbents, only Medisorb demonstrated notable $CO_2$ absorption activity.

Table 7.

| Absorbent | Duration (min) | Average total $CO_2$ absorption (L/kg) |
|---|---|---|
| AMSORB PLUS fresh 14.6% $H_2O$ | 691 | 134 |
| Medisorb fresh 15.8% $H_2O$ | 510 | 99 |
| LoFloSorb fresh 14.6% $H_2O$ | 385 | 74 |

Table 8.

| Absorbent | Duration (min) | Total $CO_2$ absorption (L/kg) |
|---|---|---|
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | 505 | 97 |
| Medisorb partially-desiccated 3.8% $H_2O$ | 445 | 85 |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | 55 | 10 |

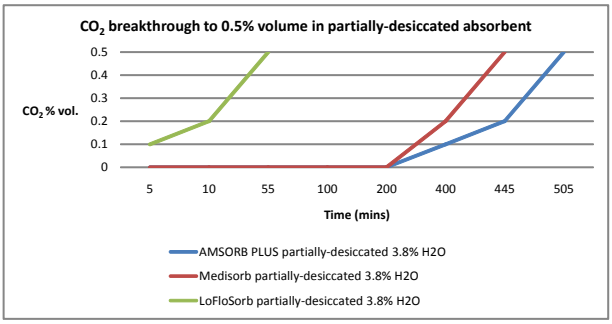
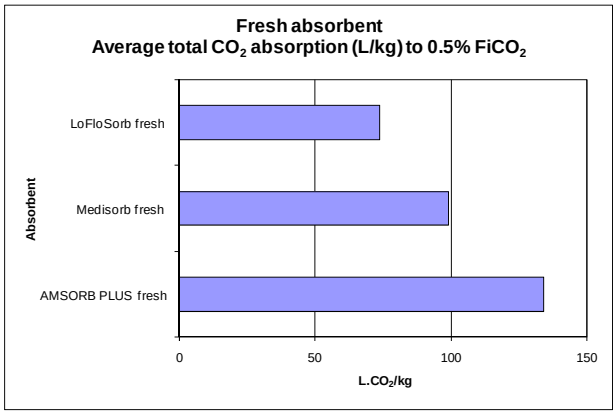
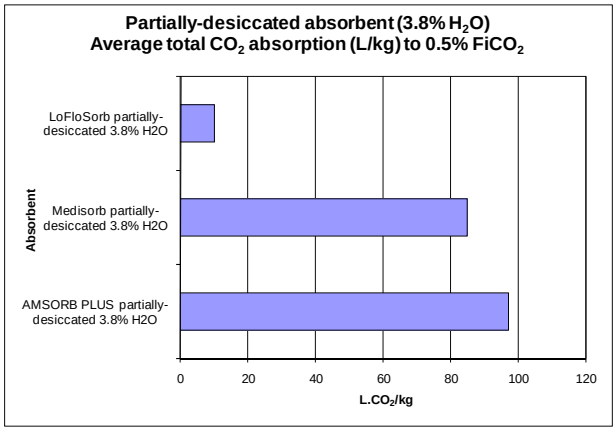
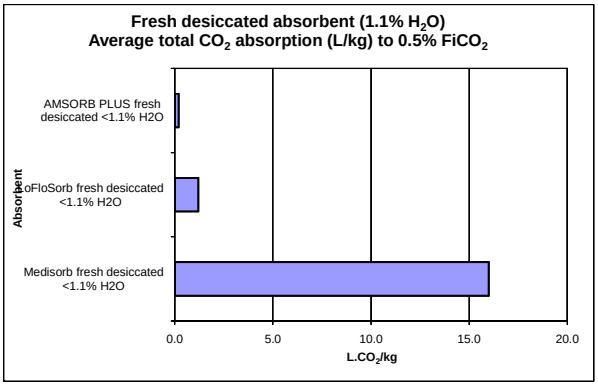



Table 9.

| Absorbent | Duration (min) | Total $CO_2$ absorption (L/kg) |
|---|---|---|
| Medisorb fresh desiccated <1.1% $H_2O$ | 85 | 16.0 |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | 7 | 1.2 |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | 1 | 0.2 |




### Temperature

Analysis of peak temperature and time to peak temperature confirmed that temperature elevation, beyond the typical observation of peak temperature in the range 36°C to 44°C during absorption of $CO_2$ with a hydrated absorbent, was statistically significant in fresh-desiccated Medisorb only (peak of 74°C after 90 minutes) and was consistent with simultaneous production of CO. Peak temperatures below 36°C were consistent with zero or minimal $CO_2$ absorption activity in fresh-desiccated AMSORB PLUS and LoFloSorb. This would support the assertion that attainment of temperatures above 36°C in these absorbents is related to $CO_2$ absorption activity, for which at least partial absorbent hydration is required, rather than any heat created by breakdown of anaesthetic agent by these absorbents, given that the levels of breakdown to CO with LoFloSorb are less, relative to levels produced by NaOH-containing absorbents.

## Methods

AMSORB PLUS and LoFloSorb were tested in their fresh state, partially-desiccated state and fresh-desiccated state, when in contact with varying percentages of isoflurane, sevoflurane and desflurane in a clinical simulation model. Individual 1.0kg ±20g samples of both materials were chosen from batches of absorbent available in a number of European and USA hospitals. Medisorb (GE Healthcare, Helsinki, Finland) was used as the control in tests.

### Conditioning of Samples

Samples were tested in their fresh state or conditioned, as appropriate. All tests were completed in triplicate and data averaged. Samples of absorbent in their fresh state were checked for moisture content, viable lime content and bulk density and placed in sealed vessels as 1.0kg ±20g batches, awaiting testing. Material, to create 1.0kg ±20g fresh-desiccated samples, was prepared from fresh absorbent samples with known moisture content and viable lime

content and bulk density and placed on a two decimal place balance (Kern & Sohn GmbH, Balingen, Germany) in a sealed vessel with inlet and outlet ports. The tared weight of the sample was recorded. Medical oxygen (BOC, UK) was passed into the vessel through the inlet port at 8L.min, exiting the outlet port until the balance showed a constant weight loss. Material to create 1.0kg ±20g partially-desiccated samples was prepared from fresh absorbent samples with known moisture content and viable lime content and bulk density and placed in the upper compartment of the circle absorber of anaesthesia machine model Narkomed 6B (Drager Medical AG, Lubeck, Germany) along with an additional 1.0kg of the same brand of fresh absorbent placed in the lower compartment of the same circle absorber. No data was recorded from the material in the lower compartment and this material was discarded after conditioning of the target material in the upper compartment. A Y-piece breathing circuit was connected to the circle absorber and a test lung (Maquet, Tyne-in-Wear, UK) substituted for a patient lung. $CO_2$ was introduced to the expiratory limb of the Y-piece circuit at 200mL.min ±10 a using mass flow controller (McMillian Company, Texas, USA). Fresh gas flow was set at 500mL.min ±50 oxygen with the anaesthesia ventilator set to deliver a tidal volume of 500mL at a respiratory rate of 12 breaths per minute. Tidal volume and minute volume were calibrated using a Wright Respirometer (Ferraris Medical Limited, Enfield, UK). Inspiratory limb gas composition was measured using a continuous capnographic gas monitor (Datex Instrumentarium, Helsinki, Finland). Testing ceased when $CO_2$ exceeded 0.5% of gas volume. The target material was placed in a sealed vessel immediately after 5g was removed for analysis of moisture and remaining viable $Ca(OH)_2$ content. Viable $Ca(OH)_2$ varied between 30% and 50% of the initial 820g/kg $Ca(OH)_2$ in the fresh absorbent, so this data was not correlated further. If required, the target material was further desiccated to 3.8% ±0.5 $H_2O$. Care was taken to cause minimal disturbance of the material during transfer to the sealed vessel. A further 5g of material was taken at 48 hours ±8 after the end of conditioning to correlate moisture and remaining viable lime data.

**Clinical Simulation Testing on Fresh and Conditioned Samples**

Fresh and conditioned samples were tested on a clinical simulation rig (see Fig. 3), specifically developed for testing $CO_2$ absorbents in simulated circle system anaesthesia, comprising a multi-vapouriser rack (1) with 'draw-over' oxygen and/or nitrous oxide fresh gas flow through gas-specific flowmeters (2). The anaesthetic vapour/fresh gas preparation was delivered into the reservoir of the collapsing bellows of an Ohio 7000 anaesthetic ventilator (4) (Ohio Medical, Wisconsin, USA) connected within a circle to the absorber assembly of anaesthesia machine model Fabius (3) (Dräger Medical, Lubeck, Germany). A 1.5m length adult Universal F breathing circuit (5) (Armstrong Medical Limited, Coleraine, Northern Ireland) connected a patient test lung (6) (Maquet Limited, Tyne-in-Wear, UK) with the Fabius absorber.

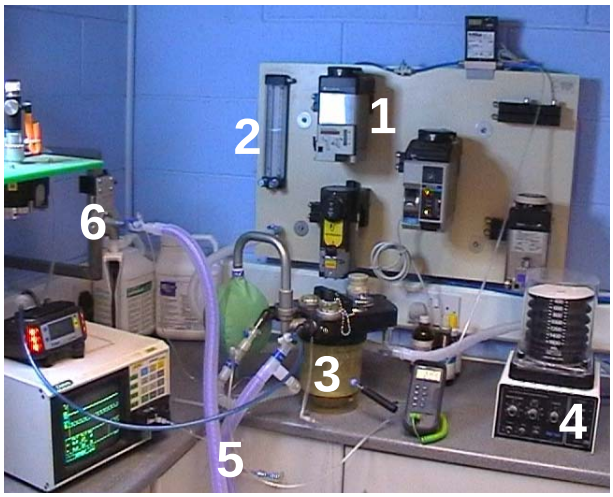



*Fig. 3. Simulation Model*

20ml $H_2O$ was dissolved in 5g calcium chloride ($CaCl_2$) and added to the test lung and the test lung immersed in a water bath, maintained at 37°C ±3, to simulate the process of pulmonary moisture exchange during low fresh gas flow anaesthesia. $CO_2$ was introduced to the expiratory limb of the Universal F circuit at 200mL.min ±10 using the mass flow controller (McMillian Company, Texas, USA). Fresh gas flow was set at 500mL.min ±50 oxygen with the anaesthesia ventilator calibrated to deliver a tidal volume of 500mL at a respiratory rate of 12 breaths per minute at ventilation peak pressure of 30cm$H_2O$ ±3. Tidal and minute volumes were calibrated using a Wright Respirometer (Ferraris Medical Limited, Enfield, UK). Testing of target samples aimed to establish the following data points through gas composition sampling, temperature profiling and visual characteristics:

**Adsorption**

1. **Fresh absorbent:** Inspiratory anaesthetic agent concentration, relative to vapouriser setting at 5, 10, 20 and 40 minutes and at the point of equilibrium of agent to 90% of the vapouriser setting
2. **Partially-desiccated absorbent:** Inspiratory anaesthetic agent concentration, relative to vapouriser setting at 5, 10, 20 and 40 minutes and at the point of equilibrium of agent to 90% of the vapouriser setting
3. **Fresh-desiccated absorbent:** Inspiratory anaesthetic agent concentration, relative to vapouriser setting at 5, 10, 20 and 40 minutes and at the point of equilibrium of agent to 90% of the vapouriser setting
4. **Fresh-desiccated absorbent:** Total loss or *adsorption* of anaesthetic agent at the point of equilibrium of agent to 90% of the vapouriser setting

**CO Production**

5. **Fresh absorbent:** CO production at 1, 5, 10, 20 and 40 minutes from fresh absorbent
6. **Partially-desiccated absorbent:** CO production at 1, 5, 10, 20 and 40 minutes from partially-desiccated absorbent
7. **Fresh-desiccated absorbent:** CO production at 1, 5, 10, 20 and 40 minutes from fresh-desiccated absorbent

**$CO_2$ Absorption Capacity, Rate of Dehydration and Permanency of Colour Change**

8-10. $CO_2$ absorption capacity of fresh absorbent, partially-desiccated absorbent and fresh-desiccated absorbent
11. Rate of dehydration
12. Permanency of colour change

Gas sampling ports (see Fig. 4) were included at (a.) the flowmeters – to verify baseline anaesthetic agent concentration; (b.) the bellows – to verify $CO_2$ baseline concentration; (c.) the expiratory limb – to measure $CO_2$ values; (d.) the inspiratory limb – to measure $CO_2$ and anaesthetic agent values; (e.) the inspiratory limb – to measure CO values. Gas composition at ports (a.), (b.), (c.) and (d.) were measured using a continuous capnograph/agent gas monitor with gas return (Datex Instrumentarium, Helsinki, Finland). Inspiratory CO values at port (e.) were measured at 1, 5, 10, 20 and 40 minutes using an infrared multi-gas detector without gas return (Drager Safety AG, Lubeck, Germany). Measurements at ports (c.) and (d.) were taken continuously for $CO_2$ and at 5, 10, 20 and 40 minutes, or at the point of equilibrium for anaesthetic agent values.

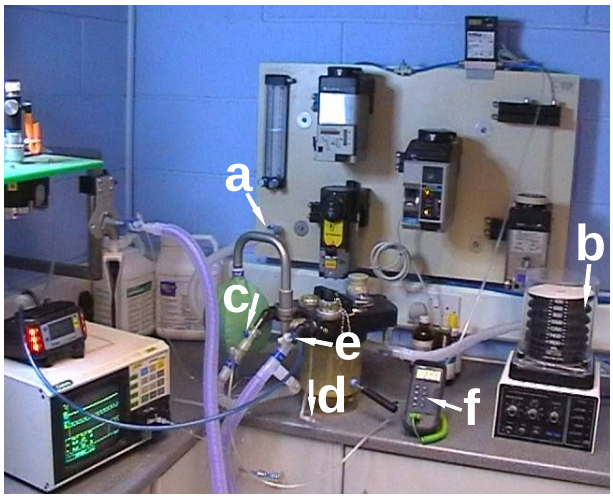



*Fig. 4. Simulation Model*

Additionally, the Fabius absorber was modified to include an access port for temperature probe (f) Tenma 72-2060, (Tenma, Inc., Ohio, USA) located at circa one third of the height of the absorber unit[6]. Location of the probe tip ensured that temperature readings were taken at 50% of the diameter of the absorber, in order to capture the temperature at the site of absorption and other chemical reactions.

For control, the simulation model was tested using agents isoflurane 2%, sevoflurane 4% and desflurane 12%, without absorbent in the canister, in order to measure any loss of anaesthetic agent or $CO_2$ or extraneous chemical reaction which might contribute erroneous data when absorbent is used in the model.

**Rate of Dehydration**

As further control and to add efficacy to the data, experiments were undertaken to assess the absorbents' ability to resist desiccation when in contact with gas flow. The manufacturer of LoFloSorb claims[7] that the addition, to their formulation, of molecular sieve zeolites and silica enables the absorbent to retain moisture to a greater extent than other absorbents, presumably supporting their claims that it does not become desiccated during use and therefore

[6] The Fabius absorber requires expiratory gas flow, through the absorbent, to be in the direction bottom-to-top
[7] Intersurgical marketing material

does not possess the ability to degrade the anaesthetic vapour through destruction of or through adsorption of the vapour, as conversely reported by Knolle. 15g±0.2 samples of fresh absorbents, LoFloSorb and AMSORB PLUS were desiccated or further hydrated to a 14% ±0.3 $H_2O$ w/w, as appropriate. These samples were conditioned in triplicate and weighed after being placed in sealed glass u-tubes with glass wool to retain the sample. After 72 hours, the contents of one u-tube of each type of absorbent sample was moisture-tested to verify the conditioned moisture content of 14% ±0.3 $H_2O$ w/w.

The remaining sample pairs were then placed individually on a four decimal place balance (Adam Equipment, Milton Keynes, UK, model ACB) and weighed to determine the gross weight of the U-tube, sample material and rubber bungs and the net weight of absorbent sample. A gas line carrying 1L.min oxygen was connected to the inlet port of the u-tube at room temperature 20°C ±0.5. The time taken to reach a steady weight (for more than 15 minutes) on the balance was recorded to determine total gravimetric weight loss of water from the sample. An identical experiment was conducted on the second of the two remaining pairs and average data, across the pairs, was recorded for final analysis. The contents of the u-tube were then moisture-analysed to verify remaining moisture content.

**Permanency of Colour Change**

Three sets of 100g samples of fresh AMSORB PLUS and LoFloSorb, which had been used in the simulation rig for $CO_2$ absorption studies, were further desiccated or hydrated to 6% $H_2O$ to ensure an even colour change to violet, across the entire 100g sample. 6% $H_2O$ was taken as the approximate hydration point where both absorbents changed from their fresh colour to violet, during $CO_2$ absorption studies on the simulation rig. This moisture content was verified using 10g of spare material produced in excess of the 100g sample. The 100g samples were immediately placed in a sealed vessel and inspected 48 hours later for deterioration of the colour.

## Results

Data points 1-12 reported in tables 10-21

**Adsorption**

1. **Fresh absorbent:** Inspiratory anaesthetic agent concentration, relative to vapouriser setting at 5, 10, 20 and 40 minutes and at the point of equilibrium of agent to 90% of the vapouriser setting
2. **Partially-desiccated absorbent:** Inspiratory anaesthetic agent concentration, relative to vapouriser setting at 5, 10, 20 and 40 minutes and at the point of equilibrium of agent to 90% of the vapouriser setting
3. **Fresh-desiccated absorbent:** Inspiratory anaesthetic agent concentration, relative to vapouriser setting at 5, 10, 20 and 40 minutes and at the point of equilibrium of agent to 90% of the vapouriser setting
4. **Fresh-desiccated absorbent:** Total loss or *adsorption* of anaesthetic agent at the point of equilibrium of agent to 90% of the vapouriser setting

**CO Production**

5. **Fresh absorbent:** CO production at 1, 5, 10, 20 and 40 minutes from fresh absorbent
6. **Partially-desiccated absorbent:** CO production at 1, 5, 10, 20 and 40 minutes from partially-desiccated absorbent
7. **Fresh-desiccated absorbent:** CO production at 1, 5, 10, 20 and 40 minutes from fresh-desiccated absorbent

**$CO_2$ Absorption Capacity, Rate of Dehydration and Permanency of Colour Change**

8-10. $CO_2$ absorption capacity of fresh absorbent, partially-desiccated absorbent and fresh-desiccated absorbent
11. Rate of dehydration
12. Permanency of colour change

Table 10. Fresh absorbent: Inspiratory anaesthetic agent concentration, relative to vapouriser setting at 5, 10, 20 and 40 minutes and at the point of equilibrium of agent to 90% of the vapouriser setting

| Absorbent | Duration (min) | Total $CO_2$ absorption (L/kg) | Agent | Time to equilibrium w/o absorbent (min) | Agent vapouriser setting (%) | agent vapouriser (%) | agent volume (mL.min) | agent % Fi at 5 min | agent % Fi at 10 min | agent % Fi at 20 min | agent % Fi at 40 min | Total time to equilibrium (min) to 90% of vapouriser setting |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Control - no absorbent in use (isoflurane)* | *0* | *0* | *Isoflurane (I)* | *<1* | *2.0%* | *2.0* | *10* | *2.00* | *2.00* | *2.00* | *2.00* | *1* |
| *Control - no absorbent in use (sevoflurane)* | *0* | *0* | *Sevoflurane (S)* | *<1* | *4.0%* | *4.0* | *20* | *4.00* | *4.00* | *4.00* | *4.00* | *1* |
| *Control - no absorbent in use (desflurane)* | *0* | *0* | *Desflurane (D)* | *<1* | *12.0%* | *12.0* | *60* | *12.00* | *12.00* | *12.00* | *12.00* | *1* |
| AMSORB PLUS fresh 14.5% $H_2O$ | 66.0 | 132 | Sevoflurane (S) | - | 4.0% | 4.0 | 20 | 2.90 | 3.60 | 3.70 | 3.90 | 8 |
| LoFloSorb fresh 14.18% $H_2O$ | 37.8 | 75.6 | Sevoflurane (S) | - | 4.0% | 4.0 | 20 | 2.00 | 2.60 | 3.10 | 3.70 | 37 |
| Medisorb fresh 15.9% $H_2O$ | 50.5 | 101 | Sevoflurane (S) | - | 4.0% | 4.0 | 20 | 2.60 | 3.30 | 3.70 | 3.90 | 13 |
| AMSORB PLUS fresh 14.9% $H_2O$ | 68.1 | 136.2 | Sevoflurane (S) | - | 8.0% | 8.0 | 40 | 5.90 | 7.20 | 7.70 | 7.90 | 8 |
| LoFloSorb fresh 14.3% $H_2O$ | 36.0 | 72 | Sevoflurane (S) | - | 8.0% | 8.0 | 40 | 4.20 | 5.10 | 7.50 | 7.90 | 28 |
| Medisorb fresh 15.4% $H_2O$ | 51.0 | 102 | Sevoflurane (S) | - | 8.0% | 8.0 | 40 | 4.50 | 5.90 | 7.50 | 7.95 | 14 |
| AMSORB PLUS fresh 14.9% $H_2O$ | 68.2 | 136.4 | Isoflurane (I) | - | 2.0% | 2.0 | 10 | 1.60 | 1.80 | 1.80 | 1.90 | 6 |
| LoFloSorb fresh 14.6% $H_2O$ | 38.5 | 77 | Isoflurane (I) | - | 2.0% | 2.0 | 10 | 1.10 | 1.05 | 1.40 | 1.88 | 38 |
| Medisorb fresh 15.8% $H_2O$ | 48.0 | 96 | Isoflurane (I) | - | 2.0% | 2.0 | 10 | 1.00 | 1.70 | 1.90 | 1.92 | 19 |
| AMSORB PLUS fresh 14.5% $H_2O$ | 66.0 | 132 | Isoflurane (I) | - | 4.0% | 4.0 | 20 | 3.10 | 3.60 | 3.80 | 3.95 | 6 |
| LoFloSorb fresh 14.20% $H_2O$ | 38.1 | 76.2 | Isoflurane (I) | - | 4.0% | 4.0 | 20 | 2.20 | 2.90 | 3.30 | 3.70 | 21 |
| Medisorb fresh 16.1% $H_2O$ | 49.2 | 98.4 | Isoflurane (I) | - | 4.0% | 4.0 | 20 | 2.80 | 3.50 | 3.60 | 3.90 | 20 |
| AMSORB PLUS fresh 14.6% $H_2O$ | 69.1 | 138.2 | Desflurane (D) | - | 12.0% | 12.0 | 60 | 9.50 | 10.80 | 11.30 | 11.80 | 7 |
| LoFloSorb fresh 14.23% $H_2O$ | 36.5 | 73 | Desflurane (D) | - | 12.0% | 12.0 | 60 | 8.80 | 10.10 | 10.80 | 11.20 | 23 |
| Medisorb fresh 15.8% $H_2O$ | 51.0 | 102 | Desflurane (D) | - | 12.0% | 12.0 | 60 | 8.95 | 9.90 | 11.10 | 11.60 | 15 |
| AMSORB PLUS fresh 14.6% $H_2O$ | 65.1 | 130.2 | Desflurane (D) | - | 16.0% | 16.0 | 80 | 12.10 | 14.40 | 15.40 | 15.80 | 5 |
| LoFloSorb fresh 14.21% $H_2O$ | 37.0 | 74 | Desflurane (D) | - | 16.0% | 16.0 | 80 | 10.90 | 12.10 | 14.40 | 15.40 | 19 |
| Medisorb fresh 15.9% $H_2O$ | 48.0 | 96 | Desflurane (D) | - | 16.0% | 16.0 | 80 | 11.05 | 13.90 | 14.80 | 15.80 | 17 |

Table 11. Partially-desiccated absorbent: Inspiratory anaesthetic agent concentration, relative to vapouriser setting at 5, 10, 20 and 40 minutes and at the point of equilibrium of agent to 90% of the vapouriser setting

| Absorbent | Duration (min) | Total $CO_2$ absorption (L/kg) | Agent | Time to equilibrium w/o absorbent (min) | Agent vapouriser setting (%) | agent vapouriser (%) | agent volume (mL.min) | agent % Fi at 5 min | agent % Fi at 10 min | agent % Fi at 20 min | agent % Fi at 40 min | Total time to equilibrium (min) to 90% of vapouriser setting |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Control - no absorbent in use (isoflurane)* | *0* | *0* | *Isoflurane (I)* | *<1* | *2.0%* | *2.0* | *10* | *2.00* | *2.00* | *2.00* | *2.00* | *1* |
| *Control - no absorbent in use (sevoflurane)* | *0* | *0* | *Sevoflurane (S)* | *<1* | *4.0%* | *4.0* | *20* | *4.00* | *4.00* | *4.00* | *4.00* | *1* |
| *Control - no absorbent in use (desflurane)* | *0* | *0* | *Desflurane (D)* | *<1* | *12.0%* | *12.0* | *60* | *12.00* | *12.00* | *12.00* | *12.00* | *1* |
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | 475 | 95 | Sevoflurane (S) | - | 4.0% | 4.0 | 20 | 2.50 | 3.20 | 3.50 | 3.85 | 21 |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | 54 | 10.8 | Sevoflurane (S) | - | 4.0% | 4.0 | 20 | 1.80 | 2.40 | 3.10 | 3.80 | 25 |
| Medisorb partially-desiccated 3.8% $H_2O$ | 420 | 84 | Sevoflurane (S) | - | 4.0% | 4.0 | 20 | 2.20 | 3.00 | 3.50 | 3.80 | 21 |
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | 501 | 100.2 | Sevoflurane (S) | - | 8.0% | 8.0 | 40 | 3.70 | 5.10 | 6.50 | 7.85 | 23 |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | 48 | 9.6 | Sevoflurane (S) | - | 8.0% | 8.0 | 40 | 2.05 | 2.80 | 4.50 | 7.30 | 37 |
| Medisorb partially-desiccated 3.8% $H_2O$ | 415 | 83 | Sevoflurane (S) | - | 8.0% | 8.0 | 40 | 3.10 | 3.90 | 5.20 | 7.70 | 31 |
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | 468 | 93.6 | Isoflurane (I) | - | 2.0% | 2.0 | 10 | 1.60 | 1.80 | 1.90 | 2.00 | 2 |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | 55 | 11 | Isoflurane (I) | - | 2.0% | 2.0 | 10 | 0.30 | 0.69 | 0.98 | 1.80 | 29 |
| Medisorb partially-desiccated 3.8% $H_2O$ | 430 | 86 | Isoflurane (I) | - | 2.0% | 2.0 | 10 | 0.90 | 1.25 | 1.60 | 1.90 | 19 |
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | 440 | 88 | Isoflurane (I) | - | 4.0% | 4.0 | 20 | 3.60 | 3.80 | 3.80 | 3.85 | 5 |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | 43 | 8.6 | Isoflurane (I) | - | 4.0% | 4.0 | 20 | 0.55 | 0.90 | 1.90 | 3.40 | 48 |
| Medisorb partially-desiccated 3.8% $H_2O$ | 390 | 78 | Isoflurane (I) | - | 4.0% | 4.0 | 20 | 1.70 | 2.50 | 3.20 | 3.80 | 31 |
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | 505 | 101 | Desflurane (D) | - | 12.0% | 12.0 | 60 | 11.65 | 11.90 | 11.90 | 11.90 | 3 |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | 61 | 12.2 | Desflurane (D) | - | 12.0% | 12.0 | 60 | 4.10 | 8.90 | 10.20 | 11.40 | 22 |
| Medisorb partially-desiccated 3.8% $H_2O$ | 445 | 89 | Desflurane (D) | - | 12.0% | 12.0 | 60 | 7.70 | 10.10 | 11.20 | 11.80 | 16 |
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | 482 | 96.4 | Desflurane (D) | - | 16.0% | 16.0 | 80 | 14.75 | 15.50 | 15.70 | 15.70 | 3 |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | 50 | 10 | Desflurane (D) | - | 16.0% | 16.0 | 80 | 6.40 | 7.90 | 11.50 | 14.10 | 43 |
| Medisorb partially-desiccated 3.8% $H_2O$ | 412 | 82.4 | Desflurane (D) | - | 16.0% | 16.0 | 80 | 6.75 | 13.30 | 14.80 | 15.50 | 13 |

Table 12. Fresh-desiccated absorbent: Inspiratory anaesthetic agent concentration, relative to vapouriser setting at 5, 10, 20 and 40 minutes and at the point of equilibrium of agent to 90% of the vapouriser setting

| Absorbent | Duration (min) | Total $CO_2$ absorption (L/kg) | Agent | Time to equilibrium w/o absorbent (min) | Agent vapouriser setting (%) | agent vapouriser (%) | agent volume (mL.min) | agent % Fi at 5 min | agent % Fi at 10 min | agent % Fi at 20 min | agent % Fi at 40 min | Total time to equilibrium (min) to 90% of vapouriser setting |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Control - no absorbent in use (isoflurane)* | *0* | *0* | *Isoflurane (I)* | *<1* | *2.0%* | *2.0* | *10* | *2.00* | *2.00* | *2.00* | *2.00* | *1* |
| *Control - no absorbent in use (sevoflurane)* | *0* | *0* | *Sevoflurane (S)* | *<1* | *4.0%* | *4.0* | *20* | *4.00* | *4.00* | *4.00* | *4.00* | *1* |
| *Control - no absorbent in use (desflurane)* | *0* | *0* | *Desflurane (D)* | *<1* | *12.0%* | *12.0* | *60* | *12.00* | *12.00* | *12.00* | *12.00* | *1* |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | 1 | 0.2 | Sevoflurane (S) | - | 4.0% | 4.0 | 20 | 1.10 | 1.80 | 3.40 | 3.90 | 24 |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | 6 | 1.2 | Sevoflurane (S) | - | 4.0% | 4.0 | 20 | 0.60 | 0.90 | 1.10 | 1.80 | 74 |
| Medisorb fresh desiccated <1.1% $H_2O$ | 80 | 16 | Sevoflurane (S) | - | 4.0% | 4.0 | 20 | 0.71 | 1.20 | 2.00 | 3.90 | 37 |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | <1 | >0.2 | Sevoflurane (S) | - | 8.0% | 8.0 | 40 | 3.10 | 4.30 | 5.70 | 7.70 | 22 |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | 6 | 1.2 | Sevoflurane (S) | - | 8.0% | 8.0 | 40 | 0.36 | 1.60 | 4.50 | 6.10 | 80 |
| Medisorb fresh desiccated <1.1% $H_2O$ | 72 | 14.4 | Sevoflurane (S) | - | 8.0% | 8.0 | 40 | 1.10 | 3.20 | 3.80 | 7.30 | 41 |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | 1 | 0.2 | Isoflurane (I) | - | 2.0% | 2.0 | 10 | 1.60 | 1.80 | 1.90 | 2.00 | 6 |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | 5 | 1 | Isoflurane (I) | - | 2.0% | 2.0 | 10 | 0.15 | 0.30 | 0.69 | 1.30 | 68 |
| Medisorb fresh desiccated <1.1% $H_2O$ | 85 | 17 | Isoflurane (I) | - | 2.0% | 2.0 | 10 | 0.23 | 0.60 | 1.20 | 1.80 | 40 |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | <1 | >0.2 | Isoflurane (I) | - | 4.0% | 4.0 | 20 | 3.60 | 3.80 | 3.95 | 3.95 | 5 |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | 7 | 1.4 | Isoflurane (I) | - | 4.0% | 4.0 | 20 | 0.70 | 1.10 | 1.90 | 2.20 | 62 |
| Medisorb fresh desiccated <1.1% $H_2O$ | 71 | 14.2 | Isoflurane (I) | - | 4.0% | 4.0 | 20 | 1.20 | 2.50 | 3.10 | 3.80 | 32 |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | <1 | >0.2 | Desflurane (D) | - | 12.0% | 12.0 | 60 | 9.20 | 10.80 | 11.30 | 11.60 | 9 |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | 6 | 1.2 | Desflurane (D) | - | 12.0% | 12.0 | 60 | 2.10 | 4.50 | 8.90 | 10.80 | 28 |
| Medisorb fresh desiccated <1.1% $H_2O$ | 80 | 16 | Desflurane (D) | - | 12.0% | 12.0 | 60 | 6.10 | 8.80 | 9.50 | 11.60 | 22 |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | 1 | 0.2 | Desflurane (D) | - | 16.0% | 16.0 | 80 | 11.80 | 14.80 | 15.60 | 15.70 | 6 |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | 6 | 1.2 | Desflurane (D) | - | 16.0% | 16.0 | 80 | 4.10 | 7.20 | 12.10 | 14.90 | 26 |
| Medisorb fresh desiccated <1.1% $H_2O$ | 68 | 13.6 | Desflurane (D) | - | 16.0% | 16.0 | 80 | 7.20 | 9.40 | 13.60 | 15.60 | 23 |

Table 13. Fresh-desiccated absorbent: Total loss or *adsorption* of anaesthetic agent at the point of equilibrium of agent to 90% of the vapouriser setting

| Absorbent | Agent | agent vapouriser (%) | agent volume (mL.min) | agent % Fi at 5 min | agent % Fi at 10 min | agent % Fi at 20 min | agent % Fi at 40 min | total time to equilibrium (min) to 90% of vapouriser setting | *agent molecular mass per mol (g)* | *agent density ($g/cc^3$)* | Cumulative agent vapour loss to 40 min (mL) | Total vapour volume inflow to 40 min | Total vapour volume loss to 40 min (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | Sevoflurane (S) | 4.0% | 20 | 1.10 | 1.80 | 3.40 | 3.90 | 24 | *200* | *1.52* | 153 | 800.0 | 19% |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | Sevoflurane (S) | 4.0% | 20 | 0.60 | 0.90 | 1.10 | 1.80 | 74 | *200* | *1.52* | 455 | 800.0 | 57% |
| Medisorb fresh desiccated <1.1% $H_2O$ | Sevoflurane (S) | 4.0% | 20 | 0.71 | 1.20 | 2.00 | 3.90 | 37 | *200* | *1.52* | 212 | 800.0 | 27% |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | Sevoflurane (S) | 8.0% | 40 | 3.10 | 4.30 | 5.70 | 7.70 | 22 | *200* | *1.52* | 303 | 1600.0 | 19% |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | Sevoflurane (S) | 8.0% | 40 | 0.36 | 1.60 | 4.50 | 6.10 | 80 | *200* | *1.52* | 629 | 1600.0 | 39% |
| Medisorb fresh desiccated <1.1% $H_2O$ | Sevoflurane (S) | 8.0% | 40 | 1.10 | 3.20 | 3.80 | 7.30 | 41 | *200* | *1.52* | 468 | 1600.0 | 29% |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | Isoflurane (I) | 2.0% | 10 | 1.60 | 1.80 | 1.90 | 2.00 | 6 | *184.5* | *1.45* | 18 | 400.0 | 4% |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | Isoflurane (I) | 2.0% | 10 | 0.15 | 0.30 | 0.69 | 1.30 | 68 | *184.5* | *1.45* | 192 | 400.0 | 48% |
| Medisorb fresh desiccated <1.1% $H_2O$ | Isoflurane (I) | 2.0% | 10 | 0.23 | 0.60 | 1.20 | 1.80 | 40 | *184.5* | *1.45* | 119 | 400.0 | 30% |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | Isoflurane (I) | 4.0% | 20 | 3.60 | 3.80 | 3.95 | 3.95 | 5 | *184.5* | *1.45* | 21 | 800.0 | 3% |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | Isoflurane (I) | 4.0% | 20 | 0.70 | 1.10 | 1.90 | 2.20 | 62 | *184.5* | *1.45* | 388 | 800.0 | 48% |
| Medisorb fresh desiccated <1.1% $H_2O$ | Isoflurane (I) | 4.0% | 20 | 1.20 | 2.50 | 3.10 | 3.80 | 32 | *184.5* | *1.45* | 150 | 800.0 | 19% |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | Desflurane (D) | 12.0% | 60 | 9.20 | 10.80 | 11.30 | 11.60 | 9 | *168* | *1.40* | 158 | 2400.0 | 7% |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | Desflurane (D) | 12.0% | 60 | 2.10 | 4.50 | 8.90 | 10.80 | 28 | *168* | *1.40* | 633 | 2400.0 | 26% |
| Medisorb fresh desiccated <1.1% $H_2O$ | Desflurane (D) | 12.0% | 60 | 6.10 | 8.80 | 9.50 | 11.60 | 22 | *168* | *1.40* | 330 | 2400.0 | 14% |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | Desflurane (D) | 16.0% | 80 | 11.80 | 14.80 | 15.60 | 15.70 | 6 | *168* | *1.40* | 175 | 3200.0 | 5% |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | Desflurane (D) | 16.0% | 80 | 4.10 | 7.20 | 12.10 | 14.90 | 26 | *168* | *1.40* | 725 | 3200.0 | 23% |
| Medisorb fresh desiccated <1.1% $H_2O$ | Desflurane (D) | 16.0% | 80 | 7.20 | 9.40 | 13.60 | 15.60 | 23 | *168* | *1.40* | 485 | 3200.0 | 15% |

Table 14. Fresh absorbent: CO production at 1, 5, 10, 20 and 40 minutes

| Absorbent | Agent | Agent vapouriser setting (%) | Peak CO (ppm) | Time to peak CO (min) | Median CO (ppm) | CO at 1 min (ppm) | CO at 5 min (ppm) | CO at 10 min (ppm) | CO at 15 min (ppm) | CO at 20 min (ppm) | CO at 40 min (ppm) | Peak temperature (°C) | Time to peak temperature (min) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AMSORB PLUS fresh 14.5% $H_2O$ | Sevoflurane (S) | 4.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 37.1 | 58.0 |
| LoFloSorb fresh 14.18% $H_2O$ | Sevoflurane (S) | 4.0% | 6 | 9 | 2 | 0 | 5 | 6 | 0 | 0 | 0 | 39.0 | 46.0 |
| Medisorb fresh 15.9% $H_2O$ | Sevoflurane (S) | 4.0% | 8 | 15 | 4 | 0 | 0 | 5 | 8 | 5 | 5 | 42.0 | 60.0 |
| AMSORB PLUS fresh 14.9% $H_2O$ | Sevoflurane (S) | 8.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 34.0 | 34.0 |
| LoFloSorb fresh 14.3% $H_2O$ | Sevoflurane (S) | 8.0% | 5 | 5 | 2 | 0 | 5 | 5 | 0 | 0 | 0 | 41.0 | 48.0 |
| Medisorb fresh 15.4% $H_2O$ | Sevoflurane (S) | 8.0% | 10 | 16 | 6 | 5 | 5 | 8 | 10 | 5 | 0 | 44.0 | 55.0 |
| AMSORB PLUS fresh 14.9% $H_2O$ | Isoflurane (I) | 2.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 36.0 | 31.0 |
| LoFloSorb fresh 14.6% $H_2O$ | Isoflurane (I) | 2.0% | 6 | 14 | 2 | 6 | 5 | 0 | 0 | 0 | 0 | 41.0 | 37.0 |
| Medisorb fresh 15.8% $H_2O$ | Isoflurane (I) | 2.0% | 20 | 5 | 5 | 2 | 20 | 10 | 0 | 0 | 0 | 43.0 | >90 |
| AMSORB PLUS fresh 14.5% $H_2O$ | Isoflurane (I) | 4.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40.0 | >60 |
| LoFloSorb fresh 14.20% $H_2O$ | Isoflurane (I) | 4.0% | 7 | 7 | 3 | 5 | 5 | 5 | 0 | 0 | 0 | 41.0 | >60 |
| Medisorb fresh 16.1% $H_2O$ | Isoflurane (I) | 4.0% | 25 | 8 | 8 | 5 | 10 | 20 | 10 | 0 | 0 | 42.0 | 54.0 |
| AMSORB PLUS fresh 14.6% $H_2O$ | Desflurane (D) | 12.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 39.0 | 43.0 |
| LoFloSorb fresh 14.23% $H_2O$ | Desflurane (D) | 12.0% | 5 | 8 | 2 | 0 | 5 | 7 | 0 | 0 | 0 | 37.4 | 27.0 |
| Medisorb fresh 15.8% $H_2O$ | Desflurane (D) | 12.0% | 35 | 12 | 20 | 10 | 20 | 25 | 30 | 20 | 15 | 45.0 | >60 |
| AMSORB PLUS fresh 14.6% $H_2O$ | Desflurane (D) | 16.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 38.0 | 33.0 |
| LoFloSorb fresh 14.21% $H_2O$ | Desflurane (D) | 16.0% | 6 | 5 | 1 | 0 | 5 | 0 | 0 | 0 | 0 | 35.0 | 21.0 |
| Medisorb fresh 15.9% $H_2O$ | Desflurane (D) | 16.0% | 45 | 10 | 23 | 15 | 20 | 45 | 20 | 20 | 15 | 42.0 | >60 |

Table 15. Partially-desiccated absorbent: CO production at 1, 5, 10, 20 and 40 minutes

| Absorbent | Agent | Agent vapouriser setting (%) | Peak CO (ppm) | Time to peak CO (min) | Median CO (ppm) | CO at 1 min (ppm) | CO at 5 min (ppm) | CO at 10 min (ppm) | CO at 15 min (ppm) | CO at 20 min (ppm) | CO at 40 min (ppm) | Peak temperature (°C) | Time to peak temperature (min) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | Sevoflurane (S) | 4.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 36.0 | 44.0 |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | Sevoflurane (S) | 4.0% | 4 | 5 | 1 | 0 | 4 | 0 | 0 | 0 | 0 | 35.0 | 50.0 |
| Medisorb partially-desiccated 3.8% $H_2O$ | Sevoflurane (S) | 4.0% | 10 | 15 | 3 | 0 | 0 | 5 | 10 | 5 | 0 | 44.0 | 65.0 |
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | Sevoflurane (S) | 8.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 38.0 | 35.0 |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | Sevoflurane (S) | 8.0% | 7 | 5 | 1 | 0 | 7 | 0 | 0 | 0 | 0 | 42.0 | 49.0 |
| Medisorb partially-desiccated 3.8% $H_2O$ | Sevoflurane (S) | 8.0% | 10 | 16 | 6 | 5 | 5 | 8 | 10 | 5 | 0 | 44.0 | 59.0 |
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | Isoflurane (I) | 2.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 37.0 | 30.0 |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | Isoflurane (I) | 2.0% | 3 | 9 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 43.0 | 57.0 |
| Medisorb partially-desiccated 3.8% $H_2O$ | Isoflurane (I) | 2.0% | 22 | 5 | 6 | 2 | 22 | 10 | 0 | 0 | 0 | 43.0 | 78.0 |
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | Isoflurane (I) | 4.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 39.0 | >60 |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | Isoflurane (I) | 4.0% | 4 | 5 | 1 | 0 | 4 | 0 | 0 | 0 | 0 | 40.0 | >60 |
| Medisorb partially-desiccated 3.8% $H_2O$ | Isoflurane (I) | 4.0% | 20 | 8 | 8 | 5 | 10 | 20 | 10 | 0 | 0 | 43.0 | >60 |
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | Desflurane (D) | 12.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 38.0 | 44.0 |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | Desflurane (D) | 12.0% | 5 | 5 | 1 | 0 | 5 | 0 | 0 | 0 | 0 | 36.0 | 31.0 |
| Medisorb partially-desiccated 3.8% $H_2O$ | Desflurane (D) | 12.0% | 35 | 12 | 20 | 10 | 20 | 25 | 30 | 20 | 15 | 46.0 | >60 |
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | Desflurane (D) | 16.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 38.0 | 38.0 |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | Desflurane (D) | 16.0% | 6 | 5 | 1 | 0 | 5 | 0 | 0 | 0 | 0 | 38.0 | 28.0 |
| Medisorb partially-desiccated 3.8% $H_2O$ | Desflurane (D) | 16.0% | 55 | 10 | 27 | 15 | 30 | 55 | 25 | 20 | 15 | 45.0 | >60 |

Table 16. Fresh-desiccated absorbent: CO production at 1, 5, 10, 20 and 40 minutes

| Absorbent | Agent | Agent vapouriser setting (%) | Peak CO (ppm) | Time to peak CO (min) | Median CO (ppm) | CO at 1 min (ppm) | CO at 5 min (ppm) | CO at 10 min (ppm) | CO at 15 min (ppm) | CO at 20 min (ppm) | CO at 40 min (ppm) | Peak temperature (°C) | Time to peak temperature (min) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | Sevoflurane (S) | 4.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 38.0 | 39.0 |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | Sevoflurane (S) | 4.0% | 35 | 12 | 23 | 7 | 15 | 35 | 30 | 20 | 30 | 37.0 | 20.0 |
| Medisorb fresh desiccated <1.1% $H_2O$ | Sevoflurane (S) | 4.0% | 350 | 38 | 237 | 70 | 180 | 220 | 280 | 320 | 350 | 52.0 | 36.0 |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | Sevoflurane (S) | 8.0% | 1 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | | |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | Sevoflurane (S) | 8.0% | 40 | 10 | 24 | 10 | 20 | 40 | 30 | 24 | 20 | 24.0 | 34.0 |
| Medisorb fresh desiccated <1.1% $H_2O$ | Sevoflurane (S) | 8.0% | 410 | 24 | 287 | 100 | 210 | 290 | 350 | 410 | 360 | 54.0 | 27.0 |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | Isoflurane (I) | 2.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 36.0 | 31.0 |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | Isoflurane (I) | 2.0% | 18 | 10 | 10 | 10 | 18 | 10 | 10 | 5 | 5 | 38.0 | 22.0 |
| Medisorb fresh desiccated <1.1% $H_2O$ | Isoflurane (I) | 2.0% | 675 | 15 | 443 | 110 | 200 | 450 | 675 | 620 | 605 | 72.2 | 18.0 |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | Isoflurane (I) | 4.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 37.0 | 36.0 |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | Isoflurane (I) | 4.0% | 48 | 8 | 28 | 15 | 30 | 45 | 35 | 20 | 20 | 41.0 | 25.0 |
| Medisorb fresh desiccated <1.1% $H_2O$ | Isoflurane (I) | 4.0% | 810 | 18 | 537 | 130 | 325 | 505 | 720 | 790 | 750 | 74.0 | 22.0 |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | Desflurane (D) | 12.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 36.7 | 31.0 |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | Desflurane (D) | 12.0% | 30 | 12 | 22 | 5 | 20 | 25 | 30 | 30 | 20 | 38.5 | 20.0 |
| Medisorb fresh desiccated <1.1% $H_2O$ | Desflurane (D) | 12.0% | 905 | 15 | 608 | 145 | 380 | 560 | 905 | 850 | 810 | 73.0 | 23.0 |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | Desflurane (D) | 16.0% | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 38.3 | 35.0 |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | Desflurane (D) | 16.0% | 35 | 9 | 17 | 5 | 11 | 33 | 20 | 20 | 15 | 36.7 | 18.0 |
| Medisorb fresh desiccated <1.1% $H_2O$ | Desflurane (D) | 16.0% | 1010 | 12 | 693 | 160 | 405 | 945 | 980 | 850 | 820 | 71.0 | 20.0 |

Table 17. $CO_2$ absorption capacity of 1.0kg fresh absorbent to 0.5%Fi $CO_2$ using 200mL.min $CO_2$ in 500mL.min oxygen at Tv 500mL/12RR

| Absorbent | Duration (min) | Total $CO_2$ absorption (L/kg) | Agent |
|---|---|---|---|
| AMSORB PLUS fresh 14.6% $H_2O$ | 691 | 138 | Desflurane (D) |
| AMSORB PLUS fresh 14.9% $H_2O$ | 682 | 136 | Isoflurane (I) |
| AMSORB PLUS fresh 14.9% $H_2O$ | 681 | 136 | Sevoflurane (S) |
| AMSORB PLUS fresh 14.5% $H_2O$ | 660 | 132 | Isoflurane (I) |
| AMSORB PLUS fresh 14.6% $H_2O$ | 651 | 130 | Desflurane (D) |
| Medisorb fresh 15.8% $H_2O$ | 510 | 102 | Desflurane (D) |
| Medisorb fresh 15.4% $H_2O$ | 510 | 102 | Sevoflurane (S) |
| Medisorb fresh 16.1% $H_2O$ | 492 | 98 | Isoflurane (I) |
| Medisorb fresh 15.9% $H_2O$ | 480 | 96 | Desflurane (D) |
| Medisorb fresh 15.8% $H_2O$ | 480 | 96 | Isoflurane (I) |
| LoFloSorb fresh 14.6% $H_2O$ | 385 | 77 | Isoflurane (I) |
| LoFloSorb fresh 14.20% $H_2O$ | 381 | 76 | Isoflurane (I) |
| LoFloSorb fresh 14.21% $H_2O$ | 370 | 74 | Desflurane (D) |
| LoFloSorb fresh 14.23% $H_2O$ | 365 | 73 | Desflurane (D) |
| LoFloSorb fresh 14.3% $H_2O$ | 360 | 72 | Sevoflurane (S) |

Table 18. $CO_2$ absorption capacity of 1.0kg partially-desiccated absorbent to 0.5%Fi $CO_2$ using 200mL.min $CO_2$ in 500mL.min oxygen at Tv 500mL/12RR

| Absorbent | Duration (min) | Total $CO_2$ absorption (L/kg) | Agent |
|---|---|---|---|
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | 505 | 101 | Desflurane (D) |
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | 501 | 100 | Sevoflurane (S) |
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | 482 | 96 | Desflurane (D) |
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | 475 | 95 | Sevoflurane (S) |
| AMSORB PLUS partially-desiccated 3.8% $H_2O$ | 468 | 94 | Isoflurane (I) |
| Medisorb partially-desiccated 3.8% $H_2O$ | 445 | 89 | Desflurane (D) |
| Medisorb partially-desiccated 3.8% $H_2O$ | 430 | 86 | Isoflurane (I) |
| Medisorb partially-desiccated 3.8% $H_2O$ | 420 | 84 | Sevoflurane (S) |
| Medisorb partially-desiccated 3.8% $H_2O$ | 415 | 83 | Sevoflurane (S) |
| Medisorb partially-desiccated 3.8% $H_2O$ | 412 | 82 | Desflurane (D) |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | 55 | 11 | Isoflurane (I) |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | 54 | 11 | Sevoflurane (S) |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | 50 | 10 | Desflurane (D) |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | 48 | 10 | Sevoflurane (S) |
| LoFloSorb partially-desiccated 3.8% $H_2O$ | 43 | 9 | Isoflurane (I) |

Table 19. $CO_2$ absorption capacity of 1.0kg fresh-desiccated absorbent to 0.5%Fi $CO_2$ using 200mL.min $CO_2$ in 500mL.min oxygen at Tv 500mL/12RR

| Absorbent | Duration (min) | Total $CO_2$ absorption (L/kg) | Agent |
|---|---|---|---|
| Medisorb fresh desiccated <1.1% $H_2O$ | 85 | 17.0 | Desflurane (D) |
| Medisorb fresh desiccated <1.1% $H_2O$ | 80 | 16.0 | Sevoflurane (S) |
| Medisorb fresh desiccated <1.1% $H_2O$ | 80 | 16.0 | Desflurane (D) |
| Medisorb fresh desiccated <1.1% $H_2O$ | 72 | 14.4 | Sevoflurane (S) |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | 7 | 1.4 | Isoflurane (I) |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | 6 | 1.2 | Sevoflurane (S) |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | 6 | 1.2 | Sevoflurane (S) |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | 6 | 1.2 | Desflurane (D) |
| LoFloSorb fresh desiccated <1.1% $H_2O$ | 6 | 1.2 | Isoflurane (I) |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | 1 | 0.2 | Desflurane (D) |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | <1 | 0.2 | Sevoflurane (S) |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | 1 | 0.2 | Isoflurane (I) |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | <1 | 0.2 | Isoflurane (I) |
| AMSORB PLUS fresh desiccated <1.1% $H_2O$ | <1 | 0.2 | Sevoflurane (S) |

**Rate of Dehydration**

(11) Both AMSORB PLUS conditioned samples had 2.15g $H_2O$ at the start of the dehydration test. 94.74% of the water was removed by dehydration within 6-hours. A constant weight was reached at 11-hours when 97.53% $H_2O$ was removed to leave moisture content of 0.4%. Both LoFloSorb conditioned samples had 2.083g $H_2O$ at the start of the dehydration test. 86.89% of the water was removed by dehydration within 6-hours. A constant weight was reached at 14 hours when 93.37% $H_2O$ was removed to leave moisture content of 0.95%.

If this data were scaled to 1.0kg fresh absorbent, AMSORB PLUS would desiccate to 0.40% $H_2O$ w/w after 733-hours exposed to 1.0L.min oxygen or 92-hours at 8.0L.min. LoFloSorb would desiccate to 0.95% $H_2O$ w/w after 932-hours exposed to 1.0L.min oxygen or 117-hours at 8.0L.min.

**Table 20. Loss of water from fresh AMSORB PLUS at 14% $H_2O$ w/w**

| AMSORB PLUS | | |
|---|---|---|
| Time (hours) | Mass Loss (g) | Water loss (%) |
| 0 | 0.000 | 0.00 |
| 0.5 | 0.405 | 18.85 |
| 1 | 0.775 | 36.08 |
| 1.5 | 1.095 | 50.98 |
| 2 | 1.420 | 66.11 |
| 2.5 | 1.580 | 73.56 |
| 3 | 1.700 | 79.14 |
| 3.5 | 1.785 | 83.10 |
| 4 | 1.895 | 88.22 |
| 5 | 2.010 | 93.58 |
| 6 | 2.035 | 94.74 |
| 7 | 2.060 | 95.90 |
| 8 | 2.070 | 96.37 |
| 9 | 2.083 | 96.97 |
| 10 | 2.090 | 97.30 |
| 11 | 2.095 | 97.53 |

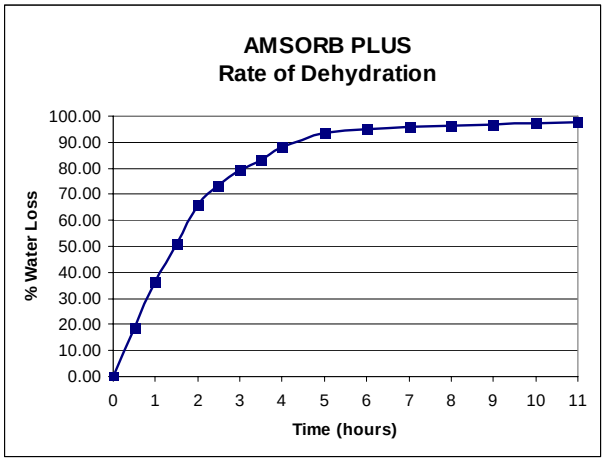



**Table 21. Loss of water from fresh LoFloSorb at 14% $H_2O$ w/w**

| LoFloSorb | | |
|---|---|---|
| Time (hours) | Mass Loss (g) | Water loss (%) |
| 0 | 0.000 | 0.00 |
| 0.5 | 0.430 | 20.64 |
| 1 | 0.755 | 36.25 |
| 1.5 | 1.020 | 48.97 |
| 2 | 1.255 | 60.25 |
| 2.5 | 1.430 | 68.65 |
| 3 | 1.580 | 75.85 |
| 3.5 | 1.675 | 80.41 |
| 4 | 1.730 | 83.05 |
| 5 | 1.770 | 84.97 |
| 6 | 1.810 | 86.89 |
| 7 | 1.830 | 87.85 |
| 9 | 1.860 | 89.29 |
| 11 | 1.910 | 91.69 |
| 14 | 1.945 | 93.37 |

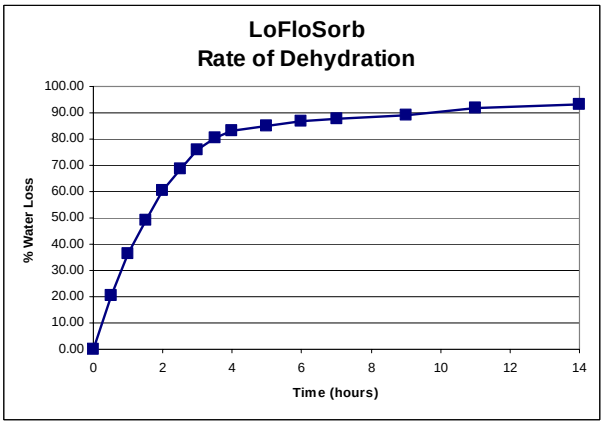



*Fig. 5. 15g LoFloSorb desiccated by oxygen*

*Fig. 6. 15g AMSORB PLUS desiccated by oxygen*

**Permanency of Colour Change**

(12) The violet colour of all three LoFloSorb samples had receded to a consistent grey-green colour, closer to its fresh colour (green) than to its indicating colour (violet). The colour of all AMSORB PLUS samples remained violet at 48-hours and 72-hours.

*Fig. 7. Exhausted LoFloSorb after 48 hours in a sealed vessel*

*Fig. 8. Exhausted AMSORB PLUS after 48 hours in a sealed vessel*

## Discussion

AMSORB PLUS is widely reported as a safe alternative to the use of soda limes or NaOH-containing absorbents during inhalational anaesthesia due to its inability to degrade anaesthetic vapour. AMSORB PLUS does not contain strong base alkali components, such as those in conventional soda lime absorbent formulations. The colour change mechanism of AMSORB PLUS appears to be an incidental benefit to its use, by providing an accurate indication of hydrated state and, hence, remaining absorptive capacity[8]. NaOH-containing absorbents are not capable of colouring or remaining coloured in response to desiccation and are therefore likely to be used inadvertently, as desiccated or partially-desiccated absorbent, on patients. The patient safety risks with use of this type of absorbent are widely known. LoFloSorb is a NSL absorbent, utilising silica and molecular sieve zeolites[9] within its formulation to aid absorption. Other studies confirm LoFloSorb produces CO and adsorbs anaesthetic vapour when desiccated. Knolle[10] reported a loss or adsorption of 89%±5 of the inflow of 0.5% isoflurane for over 60 minutes from the start of the test. This showed that desiccated LoFloSorb seriously inhibited the delivery of anaesthetic vapour and, in clinical use this could pose a serious risk to patient well-being and comfort. The capability of desiccated LoFloSorb to adsorb anaesthetic agent is therefore significant and is confirmed in this study but the present study additionally demonstrates significant adsorption of vapour when LoFloSorb is fresh or is partially-desiccated, relative to the performance of AMSORB PLUS and Medisorb. This behaviour may be due to the use of silica and zeolites in LoFloSorb, which published clinical papers[11] show entrap vapourised drugs as well as $CO_2$. A common example of this is the use of molecular sieve crystals in the scavenging system of anaesthetic machines, which adsorb waste anaesthetic vapour. The extent to which fresh or partially-desiccated LoFloSorb is capable of adsorbing anaesthetic vapour, whilst simultaneously absorbing $CO_2$ should be carefully considered before clinical use. Inadequate delivery of anaesthetic vapour to the patient especially in the early stages of anaesthesia may expose the patient to inadequate anaesthesia and surgical pain that may be masked if muscle relaxant drugs are used concomitantly. The present study did not examine what happens to adsorbed anaesthetic vapour. It is possible that such vapour condenses to liquid on the surface of absorbent material and is re-vapourised as absorbent temperature rises due to heat produced from the absorption of $CO_2$. This secondary vapourisation would add vapour to the intentional delivery of vapour via the vapouriser dial setting causing anomalies between inspired/expired values and those of the vapouriser dial setting. If undetected, patients could receive elevated and/or erratic levels of anaesthetic vapour, potentially resulting in inadvertent changes to blood pressure

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[10] Knolle E *et al.* Small Carbon Monoxide Formation in Absorbents Does Not Correlate with Small Carbon Dioxide Absorption. Anesthesia & Analgesia 2002; vol. 95; pp650-655
[11] Fee JP *et al.* Molecular Sieves: an Alternative Method of Carbon Dioxide Removal does not Generate Compound A during Simulated Low-Flow Sevoflurane Anaesthesia. Anaesthesia 1995; vol. Oct 50(10); pp841-845

and cardiac output or trigger post-operative nausea or other complications from anaesthetic over-delivery.

Data from the present study highlights the limited $CO_2$ absorption capacity of LoFloSorb when fresh or when partially-desiccated, relative to that of AMSORB PLUS and Medisorb under the same conditions, which appears to be further limited as moisture content reduces. The impact of such limited absorption capacity should be carefully considered during low fresh gas flow anaesthesia and lengthy surgical cases. All absorbents lose moisture, to varying extents, during clinical $CO_2$ absorption, which theoretically reduces absorption capacity. However, the present study suggests a ten-fold decrease in absorption capacity, when LoFloSorb is compared to AMSORB PLUS when both materials reach 3.8% $H_2O$, suggesting that the relationship between $Ca(OH)_2$, moisture and other absorbent ingredients, has a significant bearing on absorption capacity in different brands of absorbent.

The rate at which LoFloSorb becomes desiccated, *in vitro*, by oxygen, relative to the desiccation rate of AMSORB PLUS, further adds substance to this argument.

Whilst it is widely accepted that NaOH-containing absorbents pose risk to patients, if used under particular conditions, LoFloSorb, like AMSORB PLUS, is presented as an absorbent to be used where physicians are concerned about adverse reactions between the absorbent and anaesthetic vapour. This study concludes that, given the findings of this study, considered opinion should be given to the use of LoFloSorb in inhalational anaesthesia.

## Appendix A


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