doi:10.1111/anae.16044

Science Letter

The role of volatile capture technology in desflurane disposal from decommissioned vaporisers

Desflurane was withdrawn from NHS Scotland in March 2023 [1], and NHS England will follow from March 2024 [2]. As noted previously [3], decommissioning may lead to retained desflurane in vaporisers that is unsuitable for administration clinically. These vaporisers must be discharged before disposal. Emptying vaporisers by `flushing´ through an anaesthetic machine could incur a substantial carbon-equivalent footprint [1, 4].

Volatile capture technology adsorbs halogenated agents from the anaesthetic gas scavenging system onto capture material. The material can then be stored or incinerated, or the agents can be extracted. So far, this technology has yielded variable results. A clinical study using CONTRAfluran™ (ZEOSYS, Luckenwalde, Germany) with desflurane anaesthesia resulted in 25% recapture [5], whereas a bench study using the SID-Dock (SageTech Medical, Paignton, UK) with sevoflurane demonstrated 95% recapture [6].

Our pilot project evaluated the use of volatile capture technology (SageTech SID-Dock) to mitigate the environmental impact of flushing decommissioned desflurane vaporisers. Because no attempt was made to extract the desflurane, the primary outcome was mass transfer (mass gain of SID-Dock canisters/mass loss of desflurane vaporisers). An anaesthetic machine (Atlan® A350X, Dräger, Lübeck, Germany) with a circle circuit (2 l reservoir bag used as `test lung´) was used for the evaluation. The SID-Dock was integrated into the anaesthetic gas scavenging system. An infrared spectrometer (Nicolet™ iS™ 5, Thermo Fisher Scientific, Waltham, MA, USA) was added beyond the SID-Dock to measure desflurane `breakthrough´.

We located 32 decommissioned vaporisers in our Trust (31 Dräger D-Vapor® 2000, one Dräger D-Vapor® 3000), all containing desflurane. These were weighed at the start of the study using a digital scale (BT-457 CGOLDENWALL, Fengzhen, China). We planned to flush the vaporisers individually via the anaesthetic machine described above, but only the D-Vapor 3000 was compatible with the machine due to design changes in newer Dräger vaporisers and machines. Therefore, a desflurane bottle was used to drain the D-Vapor 2000 vaporisers and transfer the desflurane into the D-Vapor 3000 [4], which was used for the evaluation.

Nine combinations of fresh gas flows and desflurane concentrations were evaluated (Table 1). The vaporiser and capture canisters were weighed at the beginning and end of each test to calculate mass transfer; the system was purged between tests [6]. Because vaporiser drainage via a bottle is incomplete [1, 4], once returned to the operating theatre the vaporisers were weighed before and after flushing until no desflurane was detected, then for another 5 min. This allowed us to calculate the efficiency of the project overall.

Table 1 Mass-transfer (calculated using pre- and post-test weights) and breakthrough proportions (calculated using infrared spectrometer and gas flow data) at various flows and concentrations.

Concentration and fresh gas flow	Vaporiser mass loss; g	SID-Can mass gain; g	Mass transfer	Breakthrough
5 $l.min^{-1}$ at 3%	78.3	76.2	97%	0.7%
5 $l.min^{-1}$ at 6%	79.4	74.1	94%	0.7%
5 $l.min^{-1}$ at 9%	82.3	77.1	94%	0.4%
10 $l.min^{-1}$ at 3%	80.7	77.0	95%	1.5%
10 $l.min^{-1}$ at 6%	79.0	74.8	95%	1.1%
10 $l.min^{-1}$ at 9%	81.9	77.7	95%	0.7%
15 $l.min^{-1}$ at 3%	84.9	79.3	93%	0.6%
15 $l.min^{-1}$ at 6%	84.0	77.0	92%	0.6%
15 $l.min^{-1}$ at 9%	85.6	78.7	95%	0.5%
		Mean	94%	0.75%

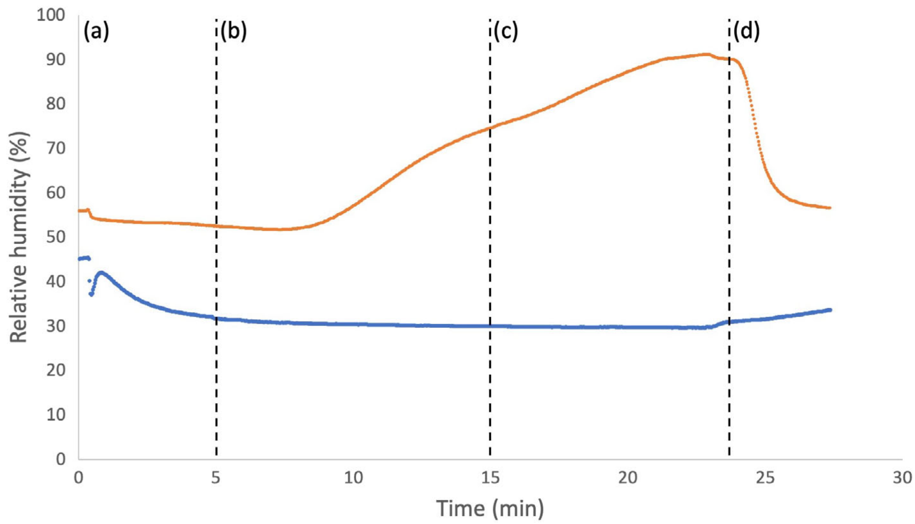

Figure 1 Relative humidity plotted against time, upstream (blue) and downstream (orange) of the SID-Dock, at 15 $l.min^{-1}$ fresh gas flow. (a) vaporiser off; (b) 9% desflurane; (c) 18% desflurane; (d) vaporiser off.

The mean mass transfer was 94%. Lower fresh gas flows and concentrations appeared marginally more efficient, though all yielded a mass transfer > 90%. The infrared spectrometer indicated a mean desflurane breakthrough of only 0.75% which was substantially lower than the mass-transfer calculations suggested. In a further experiment, we measured relative humidity upstream and downstream of the SID-Dock using electronic hygrometers (AM2302/DHT22, Adafruit, New York City, NY, USA). This demonstrated increased humidity downstream of the SID-Dock during desflurane capture (Fig. 1). The discrepancy between mass transfer and breakthrough may, therefore, be due to displacement of water from the capture material as desflurane is adsorbed.

In total, 5225 g of desflurane was vaporised through the anaesthetic machine attached to the SID-Dock. This equates to 4944 g of desflurane captured, based on the mean mass transfer of 94%. A further 1645 g, which could not be decanted from our vaporisers, was flushed following its return to the operating theatre. Therefore, we calculate an overall efficiency of 72% (4944/[5225 + 1645]) for the project. Based the 100-year global warming potential of desflurane [7], we estimate that this prevented the emission of desflurane equivalent to 12.68 tonnes of carbon dioxide. It is likely that > 90% mass transfer would have been feasible had all vaporisers been compatible, consistent with previous data on sevoflurane [6].

The SID-Dock is an efficient means of capturing desflurane when vaporisers are flushed at high concentrations and fresh gas flows. These data have important implications for responsible decommissioning. However, the disposal of captured desflurane still presents a challenge. Potential solutions include high-temperature incineration, chemical processing and photolytic destruction.

Vaporiser and anaesthetic machine incompatibility prevented us from being able to fully empty all vaporisers during the evaluation, limiting the efficiency of the project overall. This was unanticipated, as the vaporisers are universally compatible with our Dräger anaesthetic machines (Atlan, Primus®, Perseus® and Cato®). Given the diversity of vaporiser design, a centralised approach to vaporiser decommissioning may be less efficient than using volatile capture technology on an institutional level. Our observation, that water vapour is expelled from the capture medium as desflurane is adsorbed, is novel, and furthers our understanding of this technology. We hope that this work helps to inform responsible decommissioning as the UK moves towards becoming a `zero desflurane´ nation.

Acknowledgements

Presented in part at the Trainee Conference of the Association of Anaesthetists, Leeds, UK, July 2023. This work was funded by a Green Impact Microgrant from the Manchester University NHS Foundation Trust Sustainability Team. The authors thank M. Gopal, S. Wileman and C. Robertson from SageTech Medical for their advice and participation. CS is a co-opted member of the Association of Anaesthetists Environment and Sustainability Committee and Executive Editor of *Anaesthesia Reports*. No other competing interests declared.

S. Shiralkar
North West School of Anaesthesia,
Manchester, UK
Email: spshiralkar@doctors.org.uk
E. Field
Cardiff University,
Cardiff, UK
E. Murphy
Manchester University NHS Foundation Trust,
Manchester, UK
C. Shelton
Lancaster Medical School,
Lancaster, UK

References

1. Scottish Government. Making the NHS More Environmentally Friendly. 2023. https://www.gov.scot/news/making-the-nhs-more-environmentally-friendly/ (accessed 19/03/2023).
2. NHS England. *NHS Standard Contract 2023/24 Service Conditions (Full Length)*. 2023. https://www.england.nhs.uk/wp-content/uploads/2023/03/03-nhssc-fl-scs.pdf (accessed 19/03/2023).
3. Cleland J, Bill V, Williams E, Shelton C. Retained desflurane in decommissioned vaporisers: a national problem? *Anaesthesia* 2022; **78**: 651–2.
4. Hinterberg J, Beffart T, Gabriel A, Holzschneider M, Tartler TM, Schaefer MS, Kienbaum P. Efficiency of inhaled anaesthetic recapture in clinical practice. *British Journal of Anaesthesia* 2022; **129**: e79–81.
5. Vaghela M, Kay RH, Jones L, Greig P. Inhalational anaesthetics: an assessment of agent delivery and capture. *Anaesthesia* 2023; **78**: 784–5.
6. Dräger. Instructions for use: D-Vapor/D-Vapor 3000. Lübeck: Dräger. 2020. https://www.youtube.com/watch?v=GFzoeMBJlQo (accessed 16/11/2022).
7. Sulbaek Andersen MP, Nielsen OJ, Wallington TJ, Karpichev B, Sander SP. Medical intelligence article: assessing the impact on global climate from general anesthetic gases. *Anesthesia and Analgesia* 2012; **14**: 1081–5.

doi:10.1111/anae.16044