SUSTAINABLE MATERIALS INNOVATION HUB

The potential for alternative materials used to reduce the environmental impact from a pressurised meter-dose inhaler (pMDI) actuator.

Summary

After a review of the commonly available polymers based on their generic properties and the ease of recycling in the UK, we would suggest that any new actuator design considers polypropylene (PP) or polycarbonate (PC) as the best option for both reusable and recyclable systems.

We recommend that a closed loop recycling scheme is considered for an actuator designed to use a monomaterial (i.e. without dose meters or other features if they require the use of other materials) that takes into account human factors to maximise its adoption. The use of human factors within the design process would significantly enhance the understanding of how an inhaler is currently used and disposed of. This could investigate issues such as the use of geolocators or tagging technology to reduce the need for several inhalers by a user due to their frequent misplacement or loss.

For the materials used in the actuator, we consider two options most applicable:

- pMDI inhalers designed for disassembly so that the actuator can be mechanically recycled and the canister can be separated with any other additional features such as dose meters attached to that component. This would also allow for the canister, propellant gas and residual active pharmaceutical ingredient (API) to be suitably disposed / recovered; or
- the actuators are designed to be washed and reused by the user with the addition of a carry case (to reduce pocket lint or dirt ingress) and the canisters are designed with dose meters that can be recycled with the materials, propellant gas and residual API suitably disposed / recovered.

There would be an additional benefit of continuing to use the current base polymer selected for the actuator with no additional costs or carbon footprint related to a need to re-tool or build new manufacturing infrastructure.

Without industry agreement for consistency on the polymer used to make inhaler actuators and for design standards that take into account end of life treatment (e.g. multi-material actuators with additional features are permitted only if they are removed with the canister), there will be little opportunity to improve its sustainability.

Background

Currently, most inhalers supplied by the NHS in the UK are Pressurised Metered Dose Inhalers (pMDI)[1] made from polypropylene (PP), but this is not an industry standard. The pressure is supplied by a fluorinated propellant gas (commonly known as HFA) with a Global Warming Potential (GWP) of between 1300 and 2900 $kgCO_2e$ / kg.[2] The impact of inhalers is significant to the NHS and was recently highlighted as a "carbon hotspot" estimated to be 3.9% of the entire NHS carbon footprint.[3]

In 2018 a UK Parliament Environmental Audit Committee report[4] recommended that the "*NHS should set a target that by 2022 at least 50% of prescribed inhalers are low GWP*" and "*were disappointed to find that so few MDIs are disposed of responsibly. We therefore recommend that the Government should work with medical professionals, pharmacists, the pharmaceutical industry and patients to significantly improve the recycling of MDIs; this makes both environmental and economic sense. The Government should ensure that by 2020, at least 50% of MDIs are recycled.*" In the proceeding years guidance has been issued by NHS Trusts to take into account the environmental impact of inhalers when considering the right clinical choice for patients.[5]

Additionally, less than 0.5% of spent inhalers are recycled.[6] While there is no evidence of them being tracked through the UK waste system, it is assumed that the majority will be incinerated, which would result in the HFAs being thermally degraded to other chemical species. However, there is uncertainty to what those chemicals species are, but it is believed they would have a lower GWP than a direct release for any residual propellant.[7]

This report reviews the use of medical-grade polypropylene to form the actuator and considers whether there are more sustainable alternatives both for single use or reusable scenarios.

Sustainability considerations

1. Use of Recycled polymer

From our extensive but not comprehensive search there does not appear to be any regulations preventing the use of recycled content in medical devices. However, the EU requirement for traceability of materials used in devices and their packaging (ISO 11607) effectively rule out the use of recycled content throughout medical fields, other than recycling in-process waste.[8] Waste polymer from other or mixed sources is of an uncertain grade, consistency and additive levels. Furthermore, there does not appear to be a regulatory distinction drawn between devices in contact with human tissue – such as blood bags – and items supplied unsterilised such as these pMDI actuators. The use of a recycled polymer does reduce the carbon footprint and primary resources required in this case primarily crude oil.

Consequently, we recommend considering the use of recycled polymer if there is traceability of the materials via a closed loop recycling scheme.

2. Materials used in contact with the mouth

Initial research from Dsposal for reusable items in contact with the mouth showed that a wide array of materials are used from metals, glass, hard plastics, stone, ceramics to plant-derived composites, paper, wood bamboo and cane. Hard plastics are sometimes specified such as acrylic resins, PP or polyethylene.

Numerous plastics are approved for medical use, for example the FDA has approved grades of ABS, PET, Nylon, PC and PP.[9] We believe that plastics are still the most suitable materials to use for the pMDI actuator due to combination of lower carbon footprint compared to glass and metal, material strength, potential for recycling (with the correct takeback scheme) and ability to be reused several times without adverse effects.

3. Reusing actuators

The canister contains the propellant and active pharmaceutical ingredient (API). Currently the NHS dispenses pMDIs as a preassembled complete pack comprised of a single actuator and canister. More recently, systems have been introduced which supply one actuator and six canisters (eg Boehringer Ingelheim Respimat). The manufacturers claim that the Respimat has a 71% improvement in carbon footprint compared to the monthly disposable version.[10]

We recommend a modification of design to allow for a closed loop recycling scheme so that:

- pMDI inhalers can be disassembled so that the actuator and canister can be separated with materials, propellant gas and residual API suitably recovered; or
- canisters can be recycled with materials, propellant gas and residual API suitably recovered and the actuators washed and reused by the user.

4. Proportion of GWP due to the actuator

The current design of pMDI canister/actuator materials are estimated to be responsible for 3-5% of the NHS carbon footprint because of the quantity and type of HFA propellant used.[3] If the GWP of the HFA is significantly lowered or eliminated in a new model, simple calculations (based on unchanged weights of empty canister and actuator) suggest that the actuator could then be responsible for up to 25%, depending on the carbon footprint of the API. This results in the choice of polymer becoming more significant in a new model.

Potential Material Choices

Metals

Numerous alloys of aluminium or stainless steel could potentially be used to fashion an actuator. However, the GWP per unit mass of all metals will be higher than that of each of the plastics discussed below, and the mass of a metal actuator will be higher than that of a plastic one – the approximate density of stainless steel[11] is 8000kg/m^3 compared to PP[12] at 900kg/m^3. This would result in a carbon footprint for manufacture of a metal actuator being far higher. Aluminium was excluded from the evaluation due to the health risks with ingestion of the metal as it is prone to react if used as an actuator without a plastic barrier coating resulting in it being a multi-material product.

Consequently, we do not recommend metal actuators as it is most likely to lead to a higher carbon footprint or would need to be reused an order of magnitude more to start to compare to a polymer alternative.

Polymers

Table 1: a list of the main polymers and ranges of relevant properties.

Listed in approximate order of fracture toughness.

Polymer	Fracture Toughness (MPa $m^{1/2}$)	Tensile Strength (MPa)	Wear Resistance	UV resistance	Ease of Recycling
PET	4.5-5.5	48-72	Moderate	Good	Easy
Polypropylene (PP)	3.0-4.5	28-41	Moderate	Poor	Easy
Nylon	2.2-5.6	90-165	Moderate	Moderate	Difficult
Polycarbonate (PC)	2.1-4.6	60-72	Moderate	Good	Difficult
Polyurethane	1.8-5.0	31-62	Moderate	Good	Difficult
PVC	1.5-5.1	41-65	Moderate	Very good	Difficult
Polyethylene (PE)	1.4-1.7	21-45	Moderate	Poor	Easy
ABS	1.2-4.3	28-55	Poor	Moderate	Difficult
Polystyrene (PS)	0.7-1.1	36-57	Poor	Moderate	Difficult
Cellulosics	1.0-2.5	25-50	Moderate	Good	Easy

Sources: The first four data columns.[13] 'Ease of Recycling' is a SMI Hub view of the technical ease of recycling in combination with the ease of access to the required facilities.

We believe that fracture toughness, tensile strength and ease of recycling are the most important properties for actuators. Wear resistance is of limited importance as the air seal with the mouth is made with the lips, not the teeth, so the mouthpiece suffers limited attrition from hard objects. Improper use could increase wear, which could be rectified by the use of a composites e.g. graphene. However, this would result in an increase in the carbon footprint of each actuator unit and reduce the viability of the actuators being recycled. UV resistance only becomes important if actuators are envisaged to last many years and used with dozens of canisters.

The most relevant polymers will be discussed in turn.

Polypropylene (PP)

In general, actuators are currently made from PP without apparent issue, demonstrating that the combination of fracture toughness and tensile strength are perfectly adequate. One downside with PP is that, although recycling PP is easy, relatively little is actually recycled because of inadequate ability to differentiate PP from HDPE in mechanical sorting. PP is notably more flexible than most tough polymers, assisting the insertion of the canister into the actuator. However, printing on PP is not easy: the samples we have seen have trade names embossed into the surface rather than printed onto them.

Poly(ethylene terephthalate) (PET)

Most grades of PET have fracture strengths and tensile strengths higher than that of PP. PET is also far more commonly recycled. PET should therefore be a potential choice for an actuator in the future. The possible downside is that PET has the potential to be enzymatically activated[14] and can be marked more easily so may provide a more favourable conditions for bacterial growth. Alternative terephthalate copolymers such as PET-G may be more resilient, but would also decrease recyclability.

Polycarbonate (PC)

PC is highly durable and of sufficient fracture resistance and tensile strength that branded water bottles are commonly made from it: this suggests that although fracture resistance is lower than that of PP it should be perfectly adequate. PC's use in water bottles also demonstrates that while printing on PC is not easy, this can be overcome in volume production. Conventional canisters 'click' into place in the actuator: PC's rigidity may be a hindrance to this expansion/contraction/friction insertion process. There are also medical grades of PC widely used in applications such as autoinjectors, injection pens, IV connectors and some surgical tools.[15] However, PC does have a carbon footprint per kg of material that is approximately four times higher than PP. Importantly, both PC and PET also offer the opportunity for selective chemical recycling, meaning that they can be recycled back to their original monomers and produce new products that match the performance of virgin materials. This offers the potential of truly circular systems, although the technology is just emerging.

Other polymers

Nylon, Polyurethane, PVC, Polyethylene, ABS and Polystyrene are all discounted for a variety of reasons. Though dependent on formulation, in general all have lower fracture strengths than PP. PVC and PS are targeted to be eliminated from packaging plastics under the Plastics Pact: they are difficult contaminants to the recycling processes for other polymers and introducing them for actuators is unlikely to be positively received. Nylon is not conventionally recycled in the UK and is discounted for this reason. ABS is very rigid and is commonly made into structural plastic mouldings, such as keyboards and car interior components: it is also difficult to recycle.

Suitability of bio-derived and biodegradable polymers

Bio-derived polymers are essentially the same material as crude oil derived, but using a plant-based feedstock, commonly ethanol from a sugar or starch source. Whilst this reduces the reliance on a fossil source for the polymer, the growing of the plant will require fuel and fertilizers as well as the chemical plant used to synthesise the polymer requiring energy - normally from a fossil source or a mix of biomass and fossil fuels. There is also an issue with the displacement of land used to grow these crops for materials rather than food, which in turn creates pressures on food availability and increases prices. Until bio-derived polymers are manufactured using exclusively renewable energy using marginal land not grown for food they will not have a significantly lower impact compared to the same fossil derived polymer and we do not recommend its use.

Degradable polymers essentially breakdown quicker than conventional polymers through exposure to oxygen and sunlight. Cellulosic polymers degrade into environmentally inert substances over time whilst other oxo-degradable polymers create a microplastic issue if released into the environment – intentionally or unintentionally. However, these still persist in the environment for long periods of time and may be even more dangerous when they degrade into nano-sized plastics to ecosystems and human health. Degradable polymers are only recommended for use in products where there is a high risk of materials being released into the environment and we do not believe pMDI actuators are a high risk product.

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References

1 Nursing Times. Sustainability 3: how nurses can reduce the environmental impact of inhalers. https://www.nursingtimes.net/clinical-archive/respiratory-clinical-archive/sustainability-3-how-nurses-can-reduce-the-environmental-impact-of-inhalers-24-08-2020 (accessed 02/2021)

2 Myrdal, P.B., Sheth, P. & Stein, S.W., Advances in Metered Dose Inhaler Technology: Formulation Development. AAPS PharmSciTech. 2014 Apr; 15(2): 434–455. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3969484/ (accessed 02/2021)

3 Wilkinson, A.J.K., Braggins, R., Steinbach, I. & Smith, J. Costs of switching to low global warming potential inhalers. An economic and carbon footprint analysis of NHS prescription data in England. BMJ Open 2019;9:e028763. doi:10.1136/bmjopen-2018-028763

4 Progress on reducing F-gas Emissions, Fifth Report of Session 2017-19. House of Commons Environmental Audit Committee. https://publications.parliament.uk/pa/cm201719/cmselect/cmenvaud/469/469.pdf (accessed 02/2021)

5 BNSSG Area Prescribing and Medicines Optimisation Committee. August 2020. https://remedy.bnssgccg.nhs.uk/media/4460/environmental-impact-of-inhalers-august-20.pdf (accessed 02/2021)

6 GlaxoSmithKline PLC. https://uk.gsk.com/en-gb/responsibility/our-planet/complete-the-cycle/ (accessed 02/2021) 2m inhalers recycled over 9 years. Reference a above gives about 50m inhalers per year placed onto the market. Implication is that less than 0.5% are recycled.

7 Waste and Resources Action Programme. Inhalers | recycle now. Available: https://www.recyclenow.com/what-to-do-with/inhalers-0

8 Healthcare Plastics Recycling Council (hprc.og) - Circularity for Healthcare Plastics: The Challenges and Opportunities. https://40864656-dd71-4c8a-a82d-dffa36a152a5.filesusr.com/ugd/49d7a0_f370df582eb545358d2da474df6b8ac0.pdf (accessed 02/2021)

9 Colorado Plastic Products https://coloradoplastics.com/plastics-for-medical-use/ (accessed 02/2021)

10 Reduced environmental impact of a reusable soft mist inhaler Michaela Hänsel, Thomas Bambach, Herbert Wachtel European Respiratory Journal Sep 2018, 52 (suppl 62) PA1021; DOI: 10.1183/13993003.congress-2018.PA1021 https://erj.ersjournals.com/content/52/suppl_62/PA1021

11 https://www.engineeringtoolbox.com/metal-alloys-densities-d_50.html (accessed 02/2021)

12 Purell HP570R Technical Data Sheet Density @23°C (provided by Dsposal)

13 Cambridge Materials Handbook. http://www-mdp.eng.cam.ac.uk/web/library/enginfo/cueddatabooks/materials.pdf (accessed 02/2021)

14 Kawai, F., Kawabata, T. & Oda, M. Current knowledge on enzymatic PET degradation and its possible application to waste stream management and other fields. *Appl Microbiol Biotechnol* 103, 4253–4268 (2019). https://doi.org/10.1007/s00253-019-09717-y

15 Covestro AG. https://solutions.covestro.com/en/highlights/articles/stories/2020/medical-polycarbonate (accessed 02/2021)