Transfer Pipettes: Product Analysis and Re-Design

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I. Executive Summary

Transfer pipettes are a single use product, intended for liquid transfer in labs. Pipettes are manufactured using blow molding and are made from low density polyethylene (LDPE), which provides the low melting point and high elasticity required for the manufacturing and performance of the pipettes. LDPE is inexpensive and easy to fabricate, however LDPE pipettes have a significant carbon footprint during manufacturing as well as negative environmental side effects that can result after disposal. Manufacturing is based on non-renewable fossil resources produced at petrochemical plants and these carbon emissions contribute to the prevailing issue of global warming facing generations to come. In addition, substantial amounts of pipettes that are disposed every year and aren't recycled end up as non-biodegradable waste in the environment. An alternative solution is proposed using Polybutylene succinate (PBS), a biodegradable polymer with similar mechanical and thermal properties to LDPE, that can also be blow molded. PBS production can be based on renewable feedstock which lowers the carbon footprint in the manufacturing process, and as the polymer degrades it return to the nature cycle as water and CO2. Replacing the current pipettes with our suggested design would significantly reduce the carbon footprint related to LDPE manufacturing and minimize negative side effects from non-recycled waste.

II. Background

There are two kinds of pipettes for laboratory use. One is the Pasteur glass pipettes, another is the Pasteur plastic pipettes. The Pasteur glass pipettes have proven invaluable during many major chemical or biological discoveries throughout 19^{th} and 20^{th} centuries. However, their fragility and risk of breakage can be a huge problem [1]. So currently plastic pipettes are far more common.

In term of plastic pipettes, we mainly consider the disposable transfer pipettes. The disposable plastic pipettes are usually made of LDPE (Low Density Polyethylene) or sometimes HDPE (High Density Polyethylene), which is one of the simplest polymer, their chemical structure is showed in Figure 1.

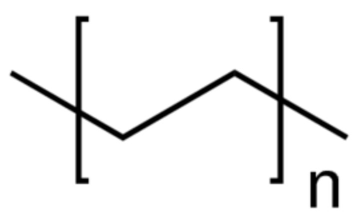

Figure 1- Chemical Structure of Polyethylene [2]

LDPE and HDPE share the same monomer, but they have different chain characteristics. The structure of LDPE is branched, while the structure of HDPE is more linear. Branched backbone means lower degree of crystallinity, which leads to lower density. HDPE has a much higher molecular weight and this results in increased Young's modulus and strength.

Plastic pipettes structure consist of the stem, which allows storage of liquid, and the bulb at the top that controls the amount of the liquid that goes into the stem. Pipettes come in a variety of shapes and sizes for different purposes, as shown in figure 2. It is important to note that the plastic pipettes are mainly used in biological and medical fields which consists mainly on working with aqueous liquids, they are not suitable for use with organic solvent as the LDPE would dissolve.

Figure 2 - Different Sizes and Shapes of Pipettes [1]

Plastic pipettes are manufactured using blow molding as shown in Figure 3. The extrusion blow molding method consist of five continues steps. First, the polymer resin is molten, then it is extruded into a preform or parison. The preform is then transferred to the final stage where the preform is inflated into a metal mold using a jet of high air pressure. The finalized product is then trimmed and any excess material is removed [4].

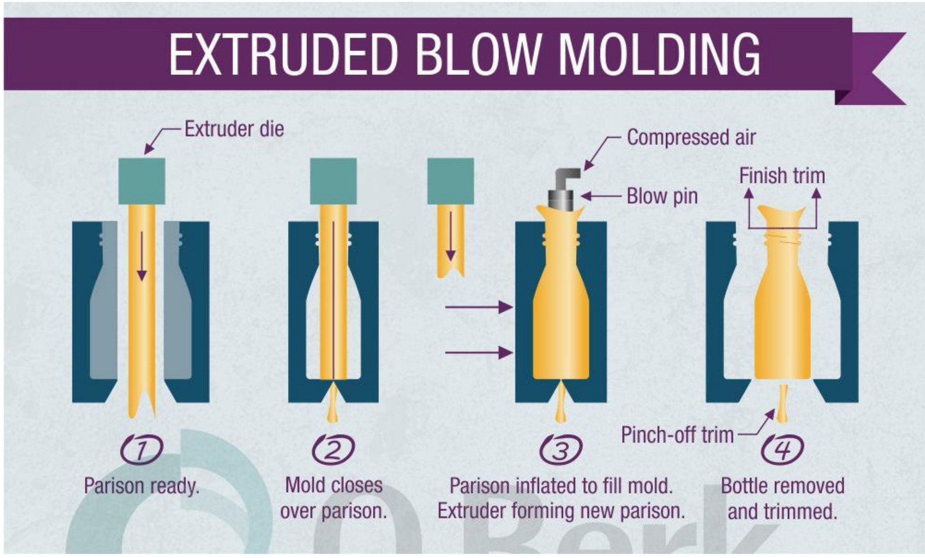

Figure 3 - Extruded Blow Molding Process [3]

III. Assessment of Carbon footprint and Recyclability Issue of Current Design

LDPE is derived from petroleum, which itself was formed from fossilized organic materials such as algae and plants being under high heat and high-pressure environment on the seabed over millions of years. Petroleum is a fossil fuel and is a nonrenewable resource. The manufacturing of plastic from petroleum starts from transporting crude oil to refineries, followed by cracking at high temperatures to form ethylene [5]. Ethylene is then compressed and cooled and sent to a reaction vessel where it is polymerized [6]. An analysis of carbon emissions associated with the manufacturing of virgin polyolefins from crude oil in the Netherlands showed that the process resulted in the emission of approximately 1687 kg CO2 per ton resin [7]. With about 100 million tons of polyethylene expected to be produced around the world in 2018 [5], LDPE production leaves a massive carbon footprint.

Out of those 100 million tons, over 1.8 million kilograms of disposable pipettes are produced each year [8]. These pipettes have an expected shelf life of three years [9], but can be around for tens to hundreds of years if stored in a cool, dry place. Disposable pipettes are intended to be used once and thrown away. While their mechanical properties allow for many uses before failure, there runs a risk of contamination and reusing is widely discouraged.

The carbon footprint of LDPE is approximately 6 kg CO2 per kg of plastic [10]. Using this, the carbon footprint of disposable pipettes produced each year can be calculated as follows:

$1\ Kg\ of\ plastic \rightarrow 6\ Kg\ CO_2$

1.8 M kg of pipettes produced per year, thus:

$1.8M\ Kg\ of\ pipettes\ X\ 6\ kg\ CO_2/\ Kg\ plastic\ = 11M\ Kg\ CO_2\ per\ year$

This staggering number can be brought down significantly with the alternative of a biomaterial used for the production of transfer pipettes, as is outlined in the following section.

IV. Alternative Design Selection

Low density polyethylene is currently used for the mass production of transfer pipettes because it is both economical to manufacture and it meets the mechanical requirements for the device. From a manufacturing perspective, LDPE is a good choice for blow molding because it has a low melting point, low molecular weight, and a relatively high heat distortion temperature. LDPE is a thermoplastic polymer that exists above its glass transition temperature at room temperature which is important for this application. It has a low tensile strength and a high elongation at break which is beneficial as the user does not need much effort to compress the bulb and the material will be able to undergo significant strain and maintain its elasticity when drawing fluid. These factors were considered when choosing a biopolymer that could replace LDPE and meet the mechanical requirements while also being feasible to blow mold. While many biopolymers were considered to replace LDPE, Polybutylene Succinate (PBS) was chosen as the best fit. A comparison of the thermal and mechanical properties is given below [11]:

Polymer	LDPE **Low density polyethylene**	PBS **Polybutylene succinate**
Tg (Celsius)	-110	-32
Tm (Celsius)	110	114
Heat Distortion Temp (Celsius)	49	97
Tensile Strength (MPa)	10	34
Elongation at break (%)	300	560
Degree of Crystallinity (%)	49	34-45

Table 1 - Mechanical and Thermal Properties of LDPE and PBS

PBS would be economical for blow molding due to its low melting point and high heat distortion temperature. It was important to pick a material that was above its glass transition temperature at room temperature. For this reason, PLA was ruled out because it would be too brittle for this application. PBS has low strength and is highly elastic and so it is a great mechanical fit for a transfer pipette.

The molecular structure of PBS is shown below in Figure 4. PBS is a biopolymer that is synthesized in a two steps process from 1-4 Butanediol (BDO) and Succinic Acid. First, excess BDO is added into succinic acid to undergo elimination reaction and form PBS oligomers. Second, oligomers are synthesized into polymer chains in vacuum condition with catalyst such as titanium and zirconium. The presence of the carboxylic acid group within PBS provides an excellent hydrolysis site and enables biodegradability. After the materials are recycled, PBS can be commercially degraded with enzyme such as lipase or microorganism such as Cryptococcus sp. at elevated temperature under 72 hours [12].

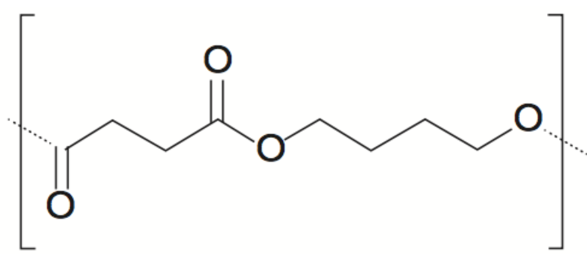

Figure 4- Chemical structure of PBS

While Succinic Acid has traditionally been produced at petrochemical plants, recent developments have allowed its production to come from renewable feedstock such as glucose, sucrose and bio based glycerol. BDO is also capable of being produced from renewable resources through fermentation of feedstock such as dextrose (glucose produced from corn) [11]. The use of renewable recourses to produce Succinic Acid and BDO has major advantage on the environmental impact because of the reduced carbon footprint. Furthermore, PBS is biodegradable and compostable; it naturally degrades into water and CO_2 [13]. PBS is a great alternative to LDPE for the production of transfer pipettes as it meets the mechanical requirements of the device while offering significant environmental advantages.

V. Analysis of function and performance of alternative design

Due to the differences in the chemical structure, PBS is more susceptible to hydrolysis reaction than LDPE. On one hand that enhances the biodegradability of PBS; on the other hand, the nature of pipette puts PBS in frequent direct contact with high grade chemicals that speed up the hydrolysis reaction. To make sure PBS based pipettes won't be degraded while transferring chemicals, established degradation data on a compound with similar chemical structure such as PLA is used to estimate hydrolysis rate of PBS. Typically, base catalyzed PLA hydrolysis takes up to 1 hour while acid catalyzed PLA hydrolysis takes up to 65 hours [14]. Transfer pipettes are mostly disposable with a very short period of lifetime (ranging from few seconds to few minutes). Although further experiments need to be done in lab to determine accurate PBS hydrolysis parameters, the preliminary estimation shows that PBS based pipettes have enough stability to transfer chemicals without being degraded.

Depending on further research into the hydrolysis of PBS, safety precautions can be taken, for example the usage time limited, and limitations on the storage environment can be put in place. Furthermore, PBS could be combined with PLA or other biodegradable polymers to tailor specific properties.

VI. Conclusion

Transfer pipettes are currently manufactured with LDPE, a material that is not biodegradable and is made from non-renewable resources. Disposable pipettes produce 11M kg of C02 per year. This paper proposes to use PBS as an alternative material to manufacture transfer pipettes. As compared to LDPE, PBS greatly improves sustainability and lowers carbon footprint while maintaining a similar mechanical function and chemical property. PBS has a low melting point and can be manufactured by blow molding, and it is a highly elastic material with a comparable strength to LDPE which will yield similar functional performance. Although PBS is more prone to hydrolysis, it would not have issues with degradation for the time scales in which these pipettes transfer fluids. Overall, PBS is a biomaterial that is an excellent alternative to LDPE for the manufacture and use of transfer pipettes.

VI. Reference

[1]. Pastette. (2017). History of Pasteur Transfer Pipettes – From Glass to Plastic. [online] Available at: http://pasteur-pipette.com/history/history-of-pasteur-pipettes/ [Accessed 26 Sep. 2017].

[2]. Sigma-Aldrich. (2017). Polyethylene (LDPE) ERMEC590. [online] Available at: http://www.sigmaaldrich.com/catalog/product/sial/ermec590?lang=en&region=US [Accessed 26 Sep. 2017].

[3]. Oberk.com. (2017). Plastic Bottle Production - What is Extrusion Blow Molding (EBM). [online] Available at: http://www.oberk.com/packaging-crash-course/what-is-extrusion-blow-molding [Accessed 26 Sep. 2017].

[4]. LyondellBasell Industries. (2015), A Guide to Polyolefin Blow Molding.

[5]. Lazonby, J. (2016). Poly(ethene) (Polyethylene). [online] Essentialchemicalindustry.org. Available at: http://www.essentialchemicalindustry.org/polymers/polyethene.html [Accessed 26 Sep. 2017].

[6]. Royal Society of Chemistry. (2002). Polythene production. Video recording. YouTube. Viewed September 25, 2017. <www.youtube.com/watch?v=U6d_F1jcKzI&t=39s>

[7]. Rem, P.C., Olsen, S., Welink, J., Fraunholez, N. (2009). Carbon dioxide emission associated with the production of plastics - a comparison of production from crude oil and recycling for the dutch case. Environmental Engineering and Management Journal. pp 978.

[8]. Coombs, A. (2008). Reuse, or recycle?. The Scientist.

[9]. RI Consumables. (2012). Pipettes Premium Quality Micropipettes.

[10]. Timeforchange.org. (2009). Plastic bags and plastic bottles - CO2 emissions during their lifetime | Time for change. [online] Available at: http://timeforchange.org/plastic-bags-and-plastic-bottles-CO2-emissions [Accessed 26 Sep. 2017].

[11]. Succinity, (2016). Polybutylene Succinate (PBS) – an innovative biopolymer for the bioplastics toolbox. [online] Available at: http://www.succinity.com/images/succinity_Broschure_A5_WEB.compressed.pdf. [Accessed 26 Sep. 2017].

[12]. Thirunavukarasu K., Purushothaman S., Sridevi J., Aarthy M., Gowthamana M.K., Nakajima-Kambe T., Kamini N.R. (2015) Degradation of poly(butylene succinate) and poly(butylene succinate-co-butylene adipate) by a lipase from yeast Cryptococcus sp. grown on agro-industrial residues. International Biodeterioration & Biodegradation. Vol 110, pp 99-107.

[13]. Xu, J. (2010). Microbial Succinic acid, its polymer poly(butylene succinate), and applications. Plastics from bacteria, pp. 347–388.

[14]. Boice, J. N., King, C. M., Higginbotham, C., & Gurney, R. W. (2008). Molecular Recycling: Application of the Twelve Principles of Green Chemistry in the Diversion of Post-consumer Poly(lactic acid) Waste. Journal of Materials Education. pp 257-280.