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Life cycle engineering of production, use and recovery of self-chilling beverage cans

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ABSTRACT

The chill-on-demand system is a new technology designed to provide cooled products on demand, thereby avoiding chilled storage. It uses the cooling effect provided by endothermic desorption of carbon dioxide previously adsorbed onto a bed of activated carbon and has the potential to be applied to any type of product that needs to be cold at the point of consumption. The principles of life cycle engineering have been utilized to evaluate the overall environmental performance of one possible application of this technology: a self-chilling beverage can, with a steel outer can to contain the beverage and an inner aluminium can to contain the adsorbent.

An attributional life cycle assessment has been undertaken considering all the life cycle stages of a self-chilling can: manufacture of each part of the beverage container, its utilization, collection of the used can, and management of the waste by reuse, recycling and landfilling. Activated carbon production is included in detail, to assess its contribution to the overall life cycle. The results are compared with those for conventional aluminium and steel beverage cans stored in two types of retail chiller: a single door refrigerator and a large open-front cooler. A sensitivity analysis explores alternative scenarios for activated carbon production and for recovery of the can components post-use for reuse or recycling. The results highlight the importance of using activated carbon produced from biomass by a process with efficient use of low-carbon electrical energy, energy recovery from waste streams and appropriate air pollution control, and of achieving high rates of recovery, re-use and recycling of the cans after use. The results suggest limited markets into which the product might be introduced, particularly where it would displace inefficient chilled storage in an electricity system with a high proportion of coal-fired generation.

1. Introduction

The chill-on-demand system is a new technology to provide rapid cooling on demand. This paper considers its application to chilling a canned beverage, i.e. to cool it to the desired temperature at the point of consumption. This technology could have the potential to disrupt the beverage market: for instance, it might be possible to reduce or even eliminate chilled storage with a consequent revolution in the whole supply chain of beverages. Thus the chill-on-demand system could possibly make a significant contribution to reducing emissions of greenhouse gases (GHGs), particularly if it displaces inefficient and poorly maintained refrigerated beverage storage cabinets or dispensers. These are common in low-income countries, frequently utilized in middle-income countries and encountered under some circumstances even in wealthy countries (Calm, 2002). This work was undertaken to explore these possibilities.

The system provides the chilling-on-demand effect by endothermic desorption of carbon dioxide previously adsorbed onto a bed of activated carbon (AC); for the beverage system, this is contained in an inner component of the can. The essential features of the device are shown schematically in Fig. 1. An outer can of tin-plated steel contains the beverage and an inner aluminium can, called the Heat Exchange Unit (HEU); only the HEU is made of aluminium because otherwise the combined can would be too expensive. The HEU contains the AC with adsorbed carbon dioxide and prevents contact between the beverage and the activated carbon. The presence of the HEU requires the self-chilling can to be

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List of acronyms

AC	Activated Carbon
ADP	Abiotic Depletion Potential
AP	Acidification Potential
BOF	Blast Oxygen Furnace
EAF	Electric Arc Furnace
EP	Eutrophication Potential
FAETP	Freshwater Aquatic Ecotoxicity Potential
GWP	Global Warming Potential
HEU	Heat Exchange Unit
HTP	Human Toxicity Potential
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LHV	Lower Heating Value
ODP	Ozone Layer Depletion Potential
OFC	Open Front Cooler
SDC	Single Door Cooler
TETP	Terrestric Ecotoxicity Potential
WMS	Waste Management System
WMS	Waste Management System

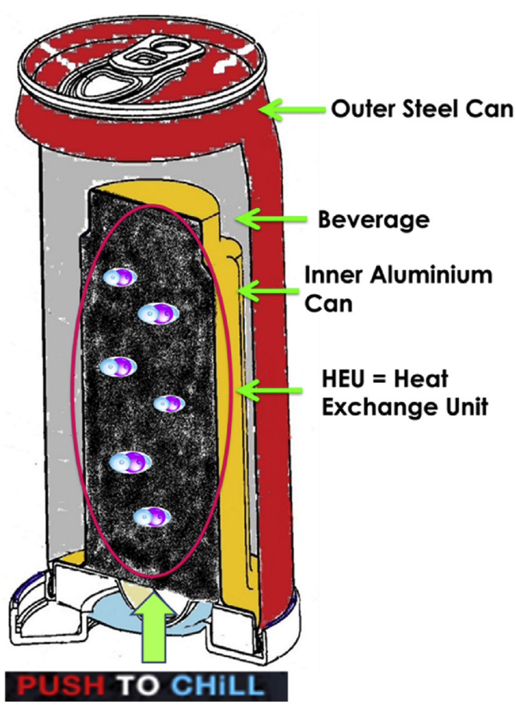

Fig. 1. Sketch of the self-chilling beverage can.

correspondingly larger than a conventional can for the same beverage volume (see Table 1). A button in the base of the can activates a valve to release the pressure inside the HEU by venting the carbon dioxide to the atmosphere; the desorption of carbon dioxide is endothermic and therefore provides a cooling action that ideally cools the beverage by about 15 °C.

The overall objective of the analysis is to devise a way to ensure the best cooling performance with minimal environmental impact at reasonable cost. An industrial ecology approach has been adopted, "considering the ecological aspect when dealing with the interaction and inter-relationship both within industrial systems and between industrial and natural systems" (Despeisse et al., 2012; Graedel and Lifset, 2015; Leigh and Li, 2015). Because of the additional materials and components, management of the self-chilling cans after use is even more important than for conventional beverage containers. Fig. 2 shows the re-use and recycling system examined here according to the principles of life cycle engineering (Peças et al., 2009; Ribeiro et al., 2008). It is assumed that the cans will be recovered after use as a separate stream; the aluminium HEU can be separated from the outer steel can and re-used while the steel can is sent to the existing steel recycling chain.

Collection, recovery, reuse, and recycling of metals and AC pellets are considered explicitly. A detailed analysis of the environmental impacts of activated carbon production from coconut shells has been developed (Arena et al., 2016) and the results, together with suggestions for possible improvements, have been incorporated in this study.

2. Methods

2.1. Product system and assessment

The goal of the study was to compare, by means of a life cycle assessment (LCA), the potential environmental impacts of the overall self-chilling beverage can system with those of the conventional approach to delivering cold beverages from chilled retail storage. The analysis aims in particular to identify scenarios in which the self-chilling system can show advantages over the conventional system, to guide product and market development. The system includes the production, use, and end-of-life phases of the cans, which are assumed to be manufactured and filled in California (USA). For the self-chilling can, the AC is assumed to be produced in Indonesia and transported to California (Arena et al., 2016). It is particularly important, from environmental and economic points of view, to design the supply system for the self-chilling can to approach "closed-loop" use of materials and, in particular, the heat exchange units: a large proportion of the cans must be recovered after use, so that the outer steel can and the inner aluminium HEU can be separated for re-use and/or recycling. The importance of recovery is explored in detail in Section 3. It is assumed that can disassembly is carried out close to the location of can manufacture and filling.

The LCA was carried out according to ISO standards (ISO-14040, 2006; ISO-14044, 2006). The functional unit is the delivery of one unit of 300 mL of chilled beverage. Since the purpose of the study is to compare self-chilling against conventional cans, an attributional approach has been adopted (Brander et al., 2009; Finnveden et al., 2009; Kua and Kamath, 2014; Thomassen et al., 2008). If the technology does prove to be successful, it will be appropriate to follow up with a consequential LCA but, at this stage, such an analysis would be too speculative to be meaningful. The life cycle environmental impacts were assessed using the CML-2001 methodology developed at the University of Leiden (Guinée et al., 2002). The following midpoint potential impacts were considered: Abiotic Depletion, Acidification, Eutrophication, Freshwater Aquatic Ecotoxicity, Terrestrial Ecotoxicity, Human Toxicity, Global Warming, Ozone Layer Depletion and Photochemical Ozone Creation. In accordance with the ISO standard 14044 (2006), normalization has been used to identify the impact categories most significant for the system under analysis. The software Gabi 6.0 was used to model the system.