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What if houses were powered by milk?

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ABSTRACT

Living architectures and green energy are hot topics of the applied sciences. They aim to develop buildings that co-live with their environment and co-habit with people they house. An ultimate goal would be to make every block in a building capable of producing energy. We present results of scoping, and somewhat illustrative, experiments on generating electrical energy in modified aerated concrete blocks. These blocks are commonly used in modern building industry and therefore make an ideal candidate for 'inbuilt' microbial bio-reactors. We fill the blocks with milk to evaluate electro-generation potential of a pasteurised milk and to study power generating potential of the medium nutrient rich for micro-organisms. We assess the practicality of using bio-reactors which become colonised by local micro-flora.

> So the girl ran further until she came to a river of milk flowing in banks of pudding. River of milk, banks of pudding, where did the swan-geese fly to?
>
> "The Magic Swan-Geese" by A.N. Tolstoy

1. Introduction

Production of green and renewable energy is amongst top priorities of the world governments (Lauber and Jacobsson, 2016; Broome and Foley, 2016; Schellnhuber et al., 2016). Microbial fuel cell technology is so far most perspective a par with solar and green energy productions (Allen and Bennetto, 1993; Logan et al., 2006; Logan, 2008; Rabaey and Verstraete, 2005). Microbial bioelectricity is considered to be a low-carbon, low-cost, sustainable potential energy solution for both developed and developing nations (Behera and Varma, 2016; Mohan et al., 2016). Bio-reactors are based on the operational principles of microbial communities. The self-governing nature of microbial communities means they are able to adapt to conditions to maintain system efficiencies by adjusting consortia. Despite having many functions, bio-reactors have recently been realised as a potential source of electricity generation: micro-organisms are cultivated in a chamber (anodic) containing aqueous media and an electrode. A second, abiotic (cathodic) electrode-containing chamber is connected to the first via a semi-permeable membrane which permits the flow of hydrogen ions ($[H^+]$). Microbes in the anodic chamber catabolise a supplied food source, which may be any readily-oxidised organic substrate, which liberates electrons and $[H^+]$. If the anodic chamber is anaerobic, the anode becomes an electron acceptor, generating a small electrical current, creating an electrochemical gradient which drives the transport of $[H^+]$ through the semi-permeable membrane (Allen and Bennetto, 1993; Logan et al., 2006; Yu and Scott, 2016).

Despite fast advances of technology power output of microbial fuel cells utilising biological material and waste is still modest (Pant et al., 2010; Sun et al., 2016; Xu et al., 2016). A solution could be to integrate fuel cells inside the buildings *en mass* where every brick or every building block is a microbial fuel cells. Such an approach well integrates in the *living architecture* aimed to produce buildings which co-live with their environment, co-habit with their occupants, and integrate living creatures and their artificial counterparts (Beesley, 2016; Armstrong, 2015, 2016).

To make a first step towards production of buildings made of microbial fuel cells we undertook a range of scoping experiments by making fuel cells from aerated concrete blocks (Celcon Block Standard Grade, 2016) and filling them with cow milk. Results of the experiments are reported in present paper.

Why choose milk? Our motive was twofold. First, to play an improvable scenario where European Common Agricultural Policy (CAP) — aimed to curb overproduction of milk and reduce budgetary deficit — will be lifted (because it is failed to achieve desirable economic effects anyway (Ang and Lansink, 2016)). And, the cow milk will be an abundant commodity in Europe, and thus will become the cheapest potential precursor of bioenergy (UNEPBW and UNEPIP, 2009; Clarke, 2010). Second, to evaluate electro-generation potential of a pasteurised milk. Milk is a weakly acidic colloid containing lipids (predominantly triacylglycerols), proteins and enzymes, polysaccharides (lactose, glucose,

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galactose) and various salts and minerals such as calcium. As such it is a rich nutrient medium for micro-organisms: raw milk typically supports complex microflora including *Lactobacillus* spp., *Streptococcus* spp., *Bifidobacterium* spp. and *Enterococcus* spp. (Gomes and Malcata, 1999; Franciosi et al., 2009). Pasteurisation is employed to greatly reduce or completely remove all microbes which would "spoil" the milk — via catabolism of desirable components such as sugars and anabolism of undesirable compounds — as well as potentially pathogenic organisms such as coliforms (Kudra and Strumillo, 1998; Van Kessel et al., 2004; Ackers et al., 2000).

Why were aerated blocks chosen? Aerated (foamed) concrete was invented in the 1920s with properties that are advantageous for constructing buildings (Alexanderson, 1979; Kurama et al., 2009; Narayanan and Ramamurthy, 2000): (a) typical compressive strength of 3.6 N/mm^2 means it can be used throughout multi-storey buildings, including solid walls, beam and block flooring systems, foundations, internal and external leaf of cavity walls, separation walls and partitions (Celcon Block Standard Grade, 2016); (b) highly thermally insulating; (c) porous structure allows for superior fire resistance; (d) workability allows accurate cutting; (e) non-toxic (no toxic gases or other toxic substances in autoclaved aerated concrete); (f) long lasting (it will not degrade under normal climate changes). Aerated cement blocks are "Semi-porous materials with open pores always include a certain percentage of moisture that affects their physical, thermal, and mechanical properties" (Drochytka et al., 2013). The typical chemical composition of aerated cement is (Malhotra, 2013): sand which contains more than 85% silica and clay (aluminium silicates); aluminium powder/paste; lime which contains 75% calcium oxide; silicon dioxide; dehydrate or phosphogypsum which contains sulfur trioxide; portland cement (calcium silicate and calcium aluminate). The properties of aerated cement blocks are conducive to the construction of bio-reactors as they can form both semi-permeable membrane(s) between chambers and the main body of the bio-reactors. These properties minimises part count which in turn reduces cost and simplifies assembly.

The paper is structured as follows. Experimental setup is introduced in Section 2. Section 3 presents results of aerobic experiments without (Section 3.1) and with electrical load (Section 3.2), and anaerobic experiments with electrical load (Section 3.3). Practicality of the approach is discussed in Section 4.

2. Methods

Microbial bio-reactors have been made inside Celcon standard aerated blocks (440 mm long, 215 mm wide and 100 mm deep) (Celcon Block Standard Grade, 2016) (Fig. 1) were made using a standard pillar drill (rated power of 500 W) with three bits in the following order: (a) drill a 55 mm deep slot with 80 mm diameter core bit; (b) drill a 60 mm deep slot with 50 mm dia core bit; (c) drill a 60 mm deep hole with 40 mm diameter hinge bit. The drilling speed was 250 rpm with vacuum dust extraction. Thus each bio-reactor consisted of an inner cylinder (volume 118 mL) with a wall circa 9.5 mm thick embedded into an outer cylinder (volume 276 mL). Volume of inner chamber was 118 mL and the outer chamber 123 mL. Electrodes were formed from 50 mm wide, plain weave, carbon fibre tape (200 g/m^2) (Carbon Fibre, 2016). The reference electrode was wrapped inside internal cylinder and the recording electrode inside outer cylinder. In experiments with load the 100 Ohm resistor was attached between the recording electrodes to make a power load (Fig. 2).

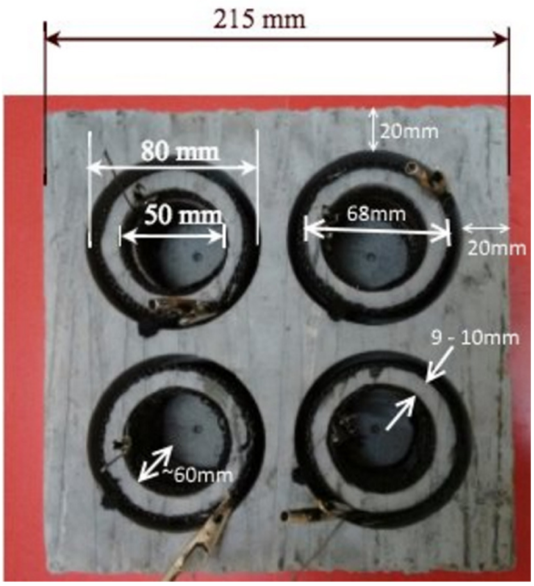

Fig. 1. Aerobic setup. View of the concrete block with four bio-reactors.

Fig. 2. Photo of one block with four aerobic bio-reactors each, in the process of recording electrical potential of the cells.

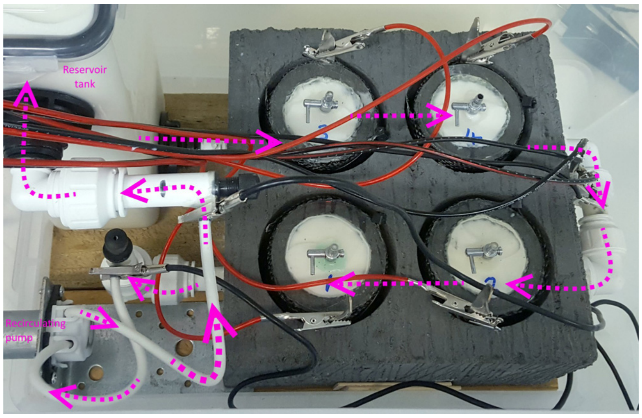

Fig. 3. Photo of anaerobic setup.

In a separate series of experiments, all anodic chambers were sealed to air in order to create an anaerobic environment (Fig. 3); the purpose of this was to compare power generation of both aerobically and anaerobically-respiring organisms. The aerated concrete blocks were modified as follows in order to seal them (Fig. 3): the anodic chambers were connected (in series) via 15 mm dia plastic tubing and the open tops of the inner cylinders were sealed with Perspex covers, containing air bleed valves (Fig. 4). The anodic chambers were connected to reservoir tank (of 2 L capacity and integrated air bleed valve) via flexible plastic piping and recirculation pump. The flow rate through the D4 peristaltic pump was