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Potential for Pathogen reduction in anaerobic digestion and biogas generation in Sub-Saharan Africa

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ABSTRACT

Current burdens of faecally derived pathogens entering the environment through untreated human and animal faeces can lead to disease, through direct handling and through contamination of water supplies used for drinking and washing. Anaerobic digestion for biogas generation in rural households in Sub-Saharan Africa has the potential to reduce pathogen loadings to the environment through treatment of livestock manures and effluent from pit latrines. However, there are limited data available for its efficacy in Sub-Saharan Africa. We review evidence from around the world and consider its application to the Sub-Saharan African situation.

1. Introduction

Microbiologically unsafe drinking water and inadequate sanitation represent a major source of infectious disease in Sub-Saharan Africa (SSA), particularly in rural areas, with as little as 15% of households (equating to more than 325 million people) being connected to an improved water supply [1,2]. The lowest coverage of sanitation is also in SSA (37% in 2004 [1]) and coverage has been declining. It is estimated that five million people lose their lives due to water-related disease each year. It has been well documented that immune-

Abbreviations: AD, anaerobic digestion; ANOVA, analysis of variance; DNA, deoxyribonucleic acid; MPN, most probable number; RNA, ribonucleic acid; SSA, Sub-Saharan Africa; VBNC, viable but not culturable; VFA, volatile fatty acids; WWTP, waste water treatment plants.

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compromised people, babies and the elderly are the most susceptible to bacterial infections [3].

Pathogen issues frequently relate to inadequate management of human and animal wastes which can lead to infection through direct contact or through polluted drinking and bathing waters and the environment. For example, the capacity of pit latrines is often exceeded or they collapse, leading to overland flow of sewage. Defaecation in the open countryside is common among rural communities. Excreta from humans and livestock, applied fresh, semi-dried or composted [4] or directly deposited by animals or humans, presents a source of faecally contaminated run-off. Health is compromised when pathogens contaminate drinking water at source, through seepage of contaminated run-off water, or within the piped distribution systems where these exist [5].

Improved sanitation has been shown to be effective in reducing disease [6]. Generating biogas through anaerobic digestion (AD) potentially leads to improved handling of human and animal excreta, vegetation and food waste and also provides treatment. As a result, it has the prospect of impacting on the spread of infectious disease mediated by these materials. It may reduce pathogen prevalence in the environment and through the food chain, and could lead to significant positive health outcomes. In order to understand the impacts upon the epidemiology of human disease, it is important to understand the efficacy of biogas digesters in reducing pathogen numbers.

2. Pathogen reduction during AD treatment

2.1. *Microorganisms of concern*

A diverse range of pathogens is present in organic wastes and manures of both human and animal origin. These include enterobacteria, enteroviruses, parasites, yeasts and fungi. Key human and animal pathogens include *Vibrio cholera*, *Salmonella* spp., *Escherichia coli* (including toxigenic forms), *Campylobacter* spp., *Listeria monocytogenes*, *Yersinia enterocolitica*, *Staphylococcus* spp., *Clostridium* spp., *Mycobacteria* spp., *Hepatitis viruses*, *Rotavirus*, *Adenovirus*, *Aspergillus* spp., *Candida* spp., *Trichophyton* spp., *Cryptosporidium*, *Giardia* and *Toxoplasma*. Many of these are zoonoses, meaning that they can be passed between animal and human populations. They are particularly prevalent among human and animal populations in developing countries and are therefore frequently found in faecal material [4,7]. Their persistence in the environment is affected by local climate, soil type, animal host prevalence, topography, land cover and management, organic waste applications and hydrology [8–12]. Human exposure to pathogens can be linked to contamination levels around the home, on the farmstead and in local water courses.

2.2. *The anaerobic digestion process*

Anaerobic digestion is increasingly being used for treatment of organic wastes in the developed world, and the majority of sewage sludge that is recycled to land in the UK is stabilized by this process. Research has therefore frequently focused on optimising process engineering for effective hygienic treatment and safe sludge disposal [13]. However, increasingly, AD is being used in Europe to manage waste while also generating heat and power. Reactors tend to be large scale, high cost enterprises in which feedstocks are provided by the waste water treatment industry, livestock wastes, abattoir wastes and food wastes [14,15]. Small-scale digesters are rare in the developed world, generally being considered unstable and not cost effective. In the developing world, however, the biogas industry is much less centralized and regulated. The most common facilities are small farm digesters running primarily on manure, which provide local cooking energy [16] and in some cases provision of lighting [17]. Uptake has tended to be slow in most African countries. For example, around 500 digesters were thought to have been installed in Ethiopia in 2006 [17]. Yongabi et al. [4] suggested that this was in part due to the cost and maintenance requirements of dome and underground digesters.

While the microbial kinetics of anaerobic microbial processes are increasingly well understood, there is relatively little information on the efficacy of the process for pathogen reduction. Indicator organisms including enteric bacteria and some specific pathogenic organisms such as *Salmonella* have historically been used to monitor the hygienic quality of sewage sludge [18] and have commonly been adopted as part of the national regulatory approaches and guidance for AD in the US and parts of Europe [19] where sewage sludge and animal by-products must meet particular criteria, including compliance with microbiological standards, prior to application to land [20–24]. Consequently, the majority of studies have tended to focus on *E. coli* and *Salmonella* [25–27]. However, these are not always representative of pathogenic microorganisms. In developing countries where applications are small scale, the stability and efficacy of the process is likely to be lower, therefore an awareness of the microbiological safety of digestate and treated sludge is essential as it has implications for human health and cycling of pathogens in the environment and through the food chain. Furthermore, there is also risk to the operators from handling of raw feedstock materials and exposure to any pathogens therein. The degree of pathogen removal achieved during AD of organic wastes is influenced by the nature of the organic waste from which the feedstock is derived along with interacting operational conditions and variables [13]. The AD process has been widely described and reviewed in a number of studies [28] and is therefore only summarized here.

AD consists of a series of microbial transformations of the feedstock that convert organic compounds to methane, carbon dioxide, and bacterial proliferation. It can be described in three stages (Fig. 1).

(1) Degradation of complex organics to simple organics (hydrolysis).
(2) Conversion of simple organics and intermediates to acetate, carbon dioxide and hydrogen (acid formation).
(3) Transformation of acetate, carbon dioxide and hydrogen to form methane and carbon dioxide (methanogenesis).

During step one, hydrolysing and fermentative microorganisms bind to particulates and colloidal materials where