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Research paper

The fixed dome digester: An appropriate design for the context of Sub-Sahara Africa?

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A B S T R A C T

The fixed dome digester design is the most deployed small scale biogas technology in sub-Sahara Africa (SSA). This design is deployed on mono-feedstock-wet anaerobic digestion (WAD) principle. Little or nothing has been reported in the literature on the sustainability in terms of the actual field operation and performance of this design within the SSA context. This study aims at bridging this gap and bringing additional insights to the scientific literature by investigating the sustainability of the Nepali–type fixed dome digester within the context of rural Cameroon. The investigations were evaluated in terms of operating parameters, biogas production, production rate and productivity of the digester. In addition the local investment cost of the design was analyzed. The design was operated on multiple-locally-available feedstock mixed with water at an average of 3:1 ratio resulting in a higher than design TS of 16%. The design, thus was operated towards the dry anaerobic digestion principle, highlighting insufficient mono-feedstock and water scarcity for a sustainable operation of the design within the context of rural SSA. The average biogas production was 1.2 m^3_{biogas}/day, giving average volumetric production rate of 0.16 $m^3_{biogas}/m^3_{digester}$ day^{-1} and yields of 0.18 m^3_{biogas}/kg VS respectively. This low performance compared with the potential mesophilic biogas production rate of 0.27 $m^3_{biogas}/m^3_{digester}$ day^{-1} could be linked to insufficient mixing of digester content and low operating temperatures. Gas storage facility (dome), skilled labour and cement made significant contributions to the investment cost of the digester. The Levelized cost of Energy from the digester was less than 1 € cents/MJ.

1. Introduction

It has been widely recognized that access to modern energy services is necessary to foster human development, protect the environment and human health. Furthermore, modern energy services will play a central role in the 2030 agenda for Sustainable Development, specifically goal N° 7 of the recently adopted UN Sustainable Development Goals (UN-SDG). Above all, access to modern energy services has become an instrumental right to the more than 2.6 billion people who currently depend on traditional use of biomass and lack access to clean and sustainable cooking facilities leading to negative consequences on both human health and environment [1–4]. Demographic growth is advanced as the main reason for the projected increase in the number of people currently dependent on traditional use of biomass by 2030. A greater proportion of these people are the poor living in rural areas of SSA [5]. Providing access to more sustainable cooking fuels and a transition towards the use of modern energy services at the level of households in rural areas of SSA will continue to be a major challenge.

A variety of improved stoves designed to burn biomass more cleanly and efficiently than traditional open fires is one of the most prominent and intermediate decentralized solution to the energy issue in Developing Countries (DC). Many stove programs have been implemented in DC, yet their adoption still remain very low, especially in SSA, notwithstanding the fact that wood is the largest biomass energy resource available for use [5]. Furthermore, debates still persist concerning the effective use and efficiencies of these stoves [6]. The main objectives of an improved cooking stove program is to achieve higher health benefits, however, it has been

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argued that for this to happen there need to be a complete shift by entire communities to alternative fuels sources different from traditional biomass (mainly firewood) [7].

Small Scale Biogas Technology presents an opportunity for a long term sustainable solution to the household energy issues in DC. Biogas technology is based on Anaerobic Digestion (AD) of organic matter to produce a mixture of gases called biogas and nutrient rich digestate [8]. This technology has several economic, social and environmental advantages [1,9,10]. The principle of AD is the same, however, several methods, depending on the climate, soils, organic matter and water availability could be used. These methods lead to the categorization of the technology and process based on critical operating parameters. These categories include [11]:

(i) Feed mode: the digesters could be batch, continuous or semi-continuous fed.
(ii) Operating temperatures: the digester could be operated under psychrophilic (0–20 °C), mesophilic (20–45 °C) or thermophilic (40–70 °C) temperature ranges.
(iii) Solid content: under this classification, the technology/process could either be Wet Anaerobic Digestion (WAD) where % TS of the influent is less than 10% or Dry Anaerobic Digestion (DAD) where the %TS of the influent is greater than 10%.
(iv) Digester Design: the digester design could be plug/cross flow, complete mix, leaching bed digesters.

By 2013, SSA still had a very low share of 38,000 out of the over 45 million domestic biogas digester disseminated in DC [8,12]. The most widely disseminated designs in DC include the Chinese fixed dome and its derivatives namely the Indian Deenbandhu, the Vietnamese fixed dome, the Nepali GGC 2047 and the plastic tubular digester [13]. Some of these designs are shown in Fig. 1. Amongst the reasons advanced for the relatively very low deployment of biogas digesters in Africa are high investment cost and insufficient feedstock [14]. Biogas digesters disseminated in DC operate on WAD principle within the mesophilic temperature range and the digester designs function either on the plug/cross flow or complete mix principle. This operation principle sets a limit to the solid content of the influent with a very high water demand (up to 90% of digester volume) imposed by the designs.

Evaluating the operation and performance of digester systems is important to assess the benefits and impacts of the technology on beneficiary communities. Such evaluations are often technical, sanitary, economic, social and environmental [13,15–29]. Moreover, the performance of digesters is an important indicator of the economic effectiveness of the investment and it affects the benefits that could be derived from the system and so influence its adoption. Under operating conditions of digester volume, temperature, hydraulic retention time, feedstock and organic loading rate, indicators often used for the evaluation of the technical performance of a digester unit include: total solid (TS) and volatile solids (VS) degradation yields, chemical oxygen demand (COD) and biological oxygen demand (BOD) abattoirs, biomethane yield (BMY), biogas production rate and [specific] productivity [18,30–32]. Economic indicators for the evaluation of digesters include: capital investment cost, payback period and Net Present Value [29,33]. Environmental indicators for the evaluation of digester performance include: GHG Emission reduction, indoor emissions, reduction in wood consumption and the Social indicators include time savings in the collection of wood [21]. The calculation of the Levelized Cost of Energy (LCOE) from energy systems could allow for an objective comparison of different sources and technologies for energy production [34].

The technical and economic performance of the tubular polyethylene, Indian fixed dome digester, floating drum and the Nepali fixed dome, operating on the WAD principle based on the afore mentioned operating conditions within different specific contexts have been reported [16,35,36]. Most of these studies do not include a detailed cost analysis of the various components of the designs which constitute investment cost and the LCOE produced from these systems. Identification of cost intensive components could lead to novel strategies for cost reduction. In SSA, the Nepali GGC2047 fixed dome is the most widely disseminated design. This digester is deployed on mono-feedstock (i.e. cow dung) and WAD principle which could present challenges in specific contexts. There is little in the literature on the sustainability in terms of the operation and technical performance of this design within the SSA context. More crucially, normal scientific literature failed to report exhaustive operational data regarding the real performances of these digesters, especially in terms of BMY and also of biogas production rate per digester volume. These two parameters are

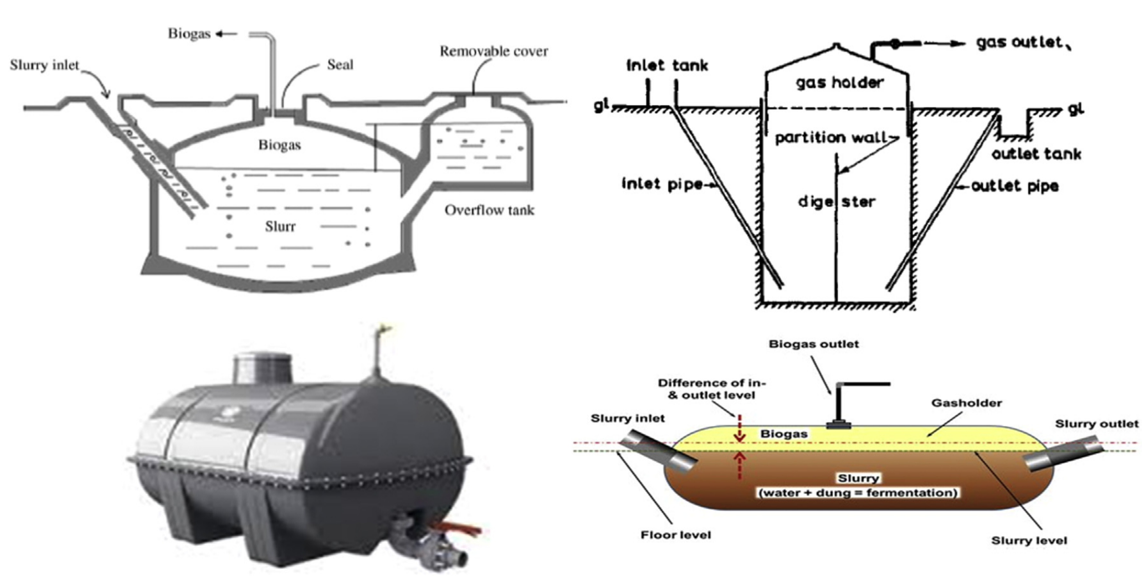

Fig. 1. Some digester designs.