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Design and cost-benefit analysis of a novel anaerobic industrial bioenergy plant in Pakistan

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ABSTRACT

The design and Cost-benefit analysis (CBA) of a novel anaerobic bioenergy plant is presented. This plant can digest various feed sources including animal-manure, vegetable-fruit wastes, poultry wastes, sugar molasses etc. The fixed dome multi-digestor system enables a continuous feed and flow mechanism. It is also equipped with a biogas purification, compression and storage system. This medium scale bioenergy plant is the first of its kind in Pakistan. It has a total installation cost of US$105,000 and annual operation and maintenance cost of US$23,400. The average energy production is 142,380 kWh per annum. With a current average energy cost of US$0.315 per kWh from all sources in Pakistan, the cost-benefit ratio is 1.2 at an internal rate of return (IRR) of 19.76%, and short payback period.

1. Introduction

Pakistan, with its population of approximately 184 million people (growing at 2.2% perannum) has a high rural population. Agriculture accounts for 25% of GDP and employs over 40% of the workforce [1]. Pakistan has a rapidly developing economy with a young population, and significantly rising energy and electricity demand, both towards transportation and industrial/domestic electricity consumption [2]. The installed generating capacity as of 2011 is 21,036 MW. Electricity demand is growing at 9% annually while supply is only at 7%, with an even higher discrepancy in summer [3]. Pakistan has a mix of electricity generation sources including thermal (gas and oil), hydroelectric and nuclear power. Renewables and coal play a minor role at the moment but are expected to increase significantly in the future, as reported [4]: the key renewable resources identified are biomass, wind and solar energy. A more recent study [5] presented an in depth analysis of the biomass potential in Pakistan. Pakistan's livestock inventory is 159 million animals producing almost 652 million kg of manure daily from cattle and buffalo only, which could in theory be used to generate 16.3 million m^3 of biogas daily and over 20 million tons of fertilizer annually. The study also cites a government program to install 10,000 domestic biogas units over the next five years, thus saving millions of $ annually in substituting fossil fuel costs. There are however significant barriers and obstacles to fully develop this potential [6–9].

The development of biogas, although started in the 1980s, remains an economic issue and a comparison with mostly natural gas and LPG will determine its growth. This paper presents a cost and benefit analysis of novel design of bioenergy plant on an industrial scale. It is the first plant of its kind in Pakistan, despite a few industrial scale bioenergy projects having been designed and implemented in the sub-continent and reported in literature [10,11] for cottage/small scale industries like milling, grinding, cutting, water pumping and in some related manufacturing activities. A study in rural India [12] reported that most rural people are not ready to accept the use of electricity generated from biomass sources, due to cost and logistical problems. A study conducted in twelve African countries on 38 bioenergy installations has indicated that economies of scale were not prominent for the small to institutional scale bioenergy plants which is opposing the general, conventional financial mindset of the industry that bigger bioenergy installations are advantageous in-terms of economies of scale. It was also concluded by the study that the technology of bioenergy is mostly independent of geographical setting of such plants [13,14]. A comparative Indian economic study [15] of 1–6 m^3

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sized biogas plants, which were of the conventional single digester with fixed dome or floating drum design, found that the installation and operational cost increased proportionally with the installed capacity of the biogas plant, irrespective of the biogas plant type. These plants have low biogas outputs of 1 m^3/25 kg i.e. 40 m^3/tonne of cow-manure as compared to our novel multidigester and lagoon based continuous flow design which produced 80–90 m^3/tonne of biogas with cow-manure. Of course, the financial payback period decreases dramatically with the increase in installed capacity. The present research follows the above said studies in assessing the systems and cost-benefit analysis of our new industrial scale bioenergy plant and this forms part of continuing research. Comparative economic studies and life cycle cost-benefit assessments are also being conducted similar to those applied in Refs. [13] and [15].

2. Plant design analysis

The current bioenergy plant design is a modified and mixed form of a fixed dome anaerobic digester (AD), continuous stirring tank reactor (CSTR) and lagoon. This design establishes a continuous feed and flow system with the ability to handle single to multiple-mixed organic feedstock, from animal manure to poultry waste and sugar molasses etc. It also has the provisions of bioenergy purification, compression and storage. A schematic of this plant is shown in Fig. 1. The actual plant picture is presented in Fig. 2. The salient design features are elaborated in the following sections.

2.1. Multistage anaerobic digester (AD) with lagoon

This experimental plant uses a fixed dome type multistage (three) anaerobic digesters each of 4.26 m (height) × 4.26m (diameter) size. These are interconnected with an underlying lagoon of the size of 26.03 m (length) × 1.52 m (width) × 1.7 m (height) to manage the continuous feed intake, slurry outflow and enhance the gas output (Fig. 3, part-b). The lagoon is directly connected with the mechanically stirred inlet tank to allow different input feedstock. All the digesters and lagoon are built of concrete. The fixed dome digesters are covered with seamless, antirust, lightweight and durable FRP (fibreglass reinforced polymer) composite domes (top covers). The gas collection (output) points are located right over each dome, and interlinked with a common piping for gas collection.

2.2. CSTR and microwave system

Digester No 1 and 3 also function as CSTR (continuous stirring tank reactors), as these are equipped with mechanical agitators, driven by an electrical motor (2 HP; 1100 RPM; 460 V). Digester 1 is also provided with an experimental microwave system of 2500 MHz frequency for which a set of electronic magnetrons of 5600 V are installed over the dome of the digestion well 1 (Fig. 1). Microwaves are only used for shorter specific time intervals of 5–10 min for rapid temperature enhancement, initiation of methanogenesis and faster decomposition of substrate molecules when fresh feedstock is inducted on daily basis.

2.3. Temperature control system

The optimal temperature of the whole system is fully sustained in the range of 35–37 °C by temperature sensors and thermostat valves based on hot water circulation, obtained from the CHP-cooling circuit of the electricity generator.

2.4. Water scrubbers and filtration system

The bioenergy scrubbing and filtration system consists of two sub-systems. The first one, prior to the compression and storage is based on three interconnected filtration chambers made of fibreglass reinforced polymer (FRP) material in cylindrical shape each having size: 2.01 m (height) × 1.21 m (diameter). These are attached with gas collection piping system (Fig. 3 and part-h) for the removal of CO_2 with the help of special water scrubbers, using 5 μm FRP composite inner dish type filters, with 10 °C water and incoming gas pressure at 2.24 MPa (325 psi). Secondly, activated carbon filter is used to eliminate certain sulphides and siloxanes from biogas [16], and silica gel filter is utilized for the removal of water contents subsequently. These filters have a useful life of 3–5 years. The cross-sectional view of the gas filtration unit is shown in Fig. 4. Air cooled medium at 6 °C is used for water-moisture removal (Figs 2 and 3 part-j).

2.5. Compression and storage system

The compression and storage system is located ahead of purification sub-system 1, where the CO_2 free biogas is compressed at up-to 2400–3000 kPa with the help of a hydraulic compression unit and then conveniently stored in the high pressure storage vessels. (Fig. 2 and 3 part-i).

2.6. Power generation set

The electrical power generation set of 150 kW (i.e. 188 kVA approx.) is located after the gas purification sub-system 2 from where it is fed with dry and pure CH_4 gas via storage vessels and pressure regulators for the power generation. The NG generator can operate with purified biogas.The gas consumption capacity of this generator set is about 58 m^3/hr. i.e. ~600 kJ/s.

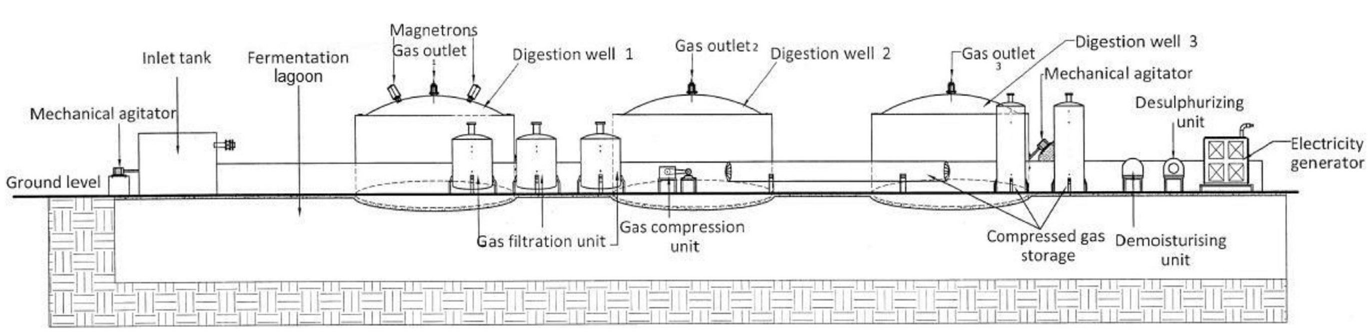

Fig. 1. Schematic of Creative bioenergy plant.