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Assessment of sustainable biogas production from de-oiled seed cake of karanja-an organic industrial waste from biodiesel industries

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HIGHLIGHTS

- A solution to reduce the disposal problem of non-edible de-oiled cakes.
- Effective utilization of de-oiled cakes for secondary energy generation.
- A solution to use the de-oiled cakes disposed from oil and biodiesel industries.
- Biogas produced from Karanja de-oiled cakes contains 73% methane.
- Digested slurry contains ingredients for the growth of crops.

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ABSTRACT

In this experimental investigation, de-oiled seed cake of Karanja (SCK), an organic industrial waste obtained from Karanja biodiesel industries was mixed with cow dung (CD) in four different proportions, viz., 75:25, 50:50, 25:75, and 0:100 percentages on a mass basis, and the mixtures were denoted as sample S_1, S_2, S_3 and S_4 respectively. The samples were kept in four different reactors and investigated simultaneously, for biogas production. Important parameters, such as the pH, temperature, hydraulic retention time (HRT), and carbon/nitrogen ratio (C/N) were evaluated and analyzed. The results indicated that sample S_3 gave best result, in comparison with the other samples, and the methane (CH_4) and carbon dioxide (CO_2) content in the biogas was found to be 73% and 17% respectively. The biogas and the slurry were characterized to observe the various properties for suitable application and the environmental impacts. The fertilizer value for S_3 was found to be better than that of other samples and the slurry became non-toxic, environmental friendly fertilizer.

1. Introduction

The gap between the energy supply and demand increases dramatically every year. In the last two decades, the absolute use of fossil fuels has increased the greenhouse gas (GHG) emission, which is a major threat to the world climate. By increasing the utilization of renewable energy sources in the place of fossil fuels, the GHG emissions can be reduced significantly. Energy from biomass has a special place among all other renewable energy sources, which is estimated to contribute 10–14% of the world's total energy demand [1]. Biodiesel is a renewable fuel and considered as one of the potential liquid alternative fuels in developing countries. It is produced from edible and non-edible oils, animal fat, and algae by the transesterification process. In India, non-edible seeds like *Pongamia pinnata* (Karanja), *Jatropha curcas* (Jatropha), *Scheleichera oleosa* (Kusum), *Azadirechta indica* (Neem), *Madhuca indica* (Mahua), *Shorea robusta* (Sal), ground nut, mustard, etc. are considered as potential feed stocks for biodiesel production [2–5]. In recent years, many pilot and commercial biodiesel plants have been installed, and are in operation worldwide; they use both edible and non-edible oils as feed stocks. De-oiled cakes of edible nature from the expeller units are generally used for cattle feed and manure preparation, while the de-oiled cakes of non-edible nature are of no use, and are disposed in the open land. The non-edible de-oiled cakes can neither be used as cattle feed nor be used directly in agricultural farming, due to their toxic nature (i.e., presence of crucin, saponins etc.). The non-edible oil cakes, dumped in the open land will generate various anthropogenic gases, such as CH_4, N_2O, H_2S, NH_3, CO_2 and volatile organic compounds (VOCs) by the action of various microorganisms, and may increase the global warming potential (GWP). The use of such waste oil cakes for

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extraction of energy is of interest today. In recent years, biogas production technology has gained growing importance, especially for utilizing biomass wastes such as crop residues, food waste, manures, industrial organic waste and high concentration waste water [6]. The generation of biogas from the de-oiled cakes would be the best solution for their effective utilization. Biogas from de-oiled cakes can provide energy for heating, cooking, lighting, and engine applications. Also, the digested slurry of the cakes can be directly used in agricultural sector for farming [7,8]. The anaerobic digestion of the de-oiled cakes can significantly reduce the harmful gaseous emissions from them. Hence, the anaerobic digestion of de-oiled cakes would be a better way of waste cake utilization for energy generation. The block diagram for the utilization of de-oiled cakes is shown in Fig. 1.

The performance of the anaerobic digestion process is a complex process, which is highly dependent on the configuration of different reactors, and varies significantly with different influential characteristics and operational conditions [9,10]. Therefore, the system must be continuously monitored and controlled, due to its instability in circumstantial conditions, particularly in terms of the biogas or methane production rates [11]. The anaerobic digestion process is highly susceptible to the fluctuation of the process inputs, such as organic loading rate (OLR), influent pH, temperature, hydraulic retention time (HRT), C/N ratio (carbon to nitrogen ratio) and toxic organic compounds (TOCs). Hence, the biogas production rate is also dependent on these applied input parameters. Therefore, the effect of these parameters involved in the digestion process may be thoroughly analyzed, for quality biogas production.

In this investigation, attempts were made to explore the possibility of producing biogas from the seed cake of Karanja (SCK), in combination with the mixed inoculum formed with cow dung (CD) operating under various environmental, organic, hydraulic and alkaline loading conditions. The objective of this study was also to evaluate the effects of various operating parameters on the biogas production under anaerobic conditions. And, the digested slurry was diagnosed to observe the fertilizer value for the growth of crops. The fuel properties of biogas were also characterized.

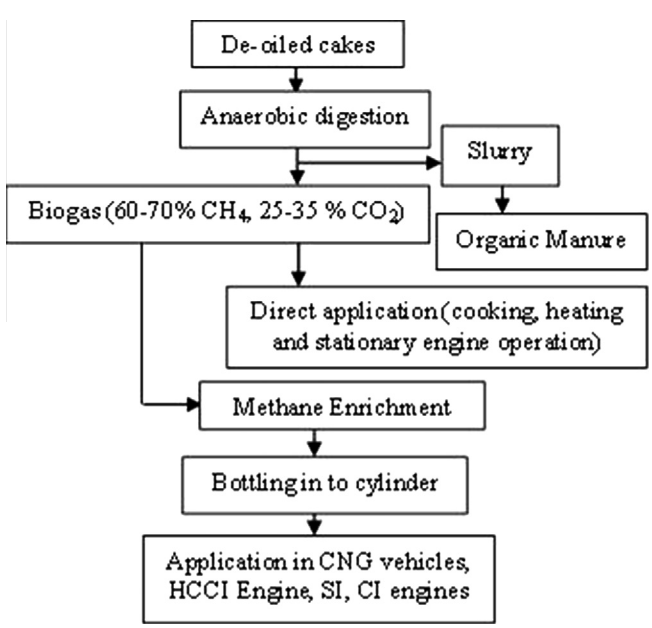

Fig. 1. Block diagram for the utilization of de-oiled cakes.

2. Materials and methods

2.1. Substrates for feed stock

The SCK was collected in the solid form from M/s Sanjay oil crusher unit, Rourkela, India. The fresh CD was collected from a cattle farm near the NIT Rourkela campus. The CD was diluted with water in a 1:1 ratio, stirred at 2000 rpm for 10 min and filtrated with a nylon grid of size 0.25 mm. The filtrate was used as the seed for anaerobic digestion. The same procedure was repeated for all the four samples with different quantities of CD. Also, about 50 gm of powdered dry rice straw with a particle size 0.12–2.2 mm was mixed with the substrate samples, for maintaining the proper C/N ratio. Rice straw was collected from the local farmer and washed with water. Then, the washed rice straw was dried in an electric oven, heating range of 20–450 °C, at 90 °C for 5 h at a heating rate of 10 °C/min. The dried straw was ground in a straw grinding mill of model NBM-36, 3.5 kW power at 1500 rpm to make an amorphous substrate, which can be easily mixed with the SCK–CD samples.

2.2. Preparation of feed materials

Experiments were conducted with samples S_1, S_2, S_3 and S_4 in four different reactors, namely, A, B, C and D respectively, for carrying out the anaerobic digestion of SCK–CD for 30 days of HRT. The SCK and CD were taken on a weight basis and mixed to get the mixtures. The dilution ratio of SCK and water was taken as 1:3.5 on a weight basis. In general, the CD is a commonly used feed stock for the production of biogas; hence, the CD slurry was also taken as one of the samples for observation, and the results obtained from samples S_1, S_2 and S_3 were compared with those of S_4 and presented. Table 1 gives the ultimate analysis of SCK, CD and rice straw. Fig. 2 shows the experimental setup used for biogas production.

It can be observed from Table 1 that, the C/N ratios for the SCK and CD were 13.82:1 and 21.76:1 respectively. But, for an optimum biogas production, the C/N ratio should be within 20–30:1 [12,13]. Hence, during the preparation of samples, rice straw with a higher C/N ratio of 84:1 was mixed with S_1, S_2 and S_3. The measured quantity of 50 gm ground rice straw was mixed with the SCK–CD mixture to maintain the C/N ratio. The C/N ratio for S_4 was found to be 21.76:1; hence, rice straw was not mixed with this sample. The TS (total solid), VS (volatile solid), FC (fixed carbon) and non-volatile solid present in the SCK, CD and rice straw are given in Table 2.

2.3. Experimental design

Initially, a measured quantity of SCK and CD were taken and mixed with water in the proportions of 1:3.5 and 1:1. Powdered rice straw was added to all the samples, except S_4. The ultimate analysis of the samples was done, and it was found that, the C/N ratios were about 19.7:1, 21.6:1, 24.7:1 and 21.7:1 for samples S_1, S_2, S_3 and S_4 respectively, as given in Table 3. From the analysis, it was observed that the C/N ratios for S_1, S_2 and S3 were comparable with that of sample S_4 which was in the desired range of 20–30:1 for optimum biogas production. The total volume of the inoculum for each sample was measured with a cylindrical measuring tube. The pH of the samples was measured with the help of a pH meter (model Crison 20) for a HRT of 30 days. The initial pH for the four samples S_1, S_2, S_3 and S_4 were found to be 5.2, 5.5, 5.6 and 6.5 respectively. Various characteristic functional groups present in the inoculums were identified by using Perkin Elmer RX Fourier Transform Infrared spectroscopy (FTIR). The FTIR spectra were collected in the range of 400–4000 cm^{-1} region with