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# Multi-response optimization of process parameters in biogas production from food waste using Taguchi – Grey relational analysis

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ABSTRACT

In the present study, the influence of process parameters and pretreatment on biogas production, volatile solid degradation and COD degradation during anaerobic digestion of food waste were experimentally investigated. Using Taguchi based Grey relational analysis, the optimum condition for anaerobic digestion was found. Taguchi technique was coupled with grey relational analysis to obtain a grey relational grade for evaluating multiple outputs. A $L_{16}$ orthogonal array was selected and designed for five parameters varied through four levels by applying Taguchi's design of experiments. The optimum level values of parameters obtained for anaerobic digestion of food waste is solid concentration of 7.5% TS, pH of 7, temperature of 50 °C, C/N ratio of 20.19 and ultrasonication pretreatment. Percentage contribution of input parameters on output was determined using ANOVA. The results showed that pretreatment is the prominent parameter that contributes towards output responses followed by pH, solid concentration, temperature and C/N ratio.



## 1. Introduction

In the current context of energy shortage and climate change, the development of renewable and sustainable energy has become an important global strategy [1]. It is accepted widely nowadays that increased use of fossil fuels as primary energy source becomes unsustainable, due to its contribution towards environmental pollution and scarcity [2]. Therefore, to overcome the above said issues, research towards clean, efficient and sustainable energy source is essential. Conversion of biomass (organic waste) into biogas by anaerobic digestion is one of the solutions to solve both energy and environmental issues. Anaerobic digestion process of biogas production from biomass and organic waste is considered as a cost effective way of renewable energy generation without increasing atmospheric carbon dioxide concentration [3,4].

Four major stages in anaerobic digestion are: hydrolysis, acidogenesis, acetogenesis and methanogenesis [2,5]. Each one of them involves specific bacteria species responsible for the conversion of high molecular structures into simpler ones, which in consequence leads to biogas production with high methane content [6]. Typical substrates for the anaerobic digestion processes are organic wastes, both municipal and industrial wastes, agricultural wastes and crop residues, animal wastes, aquatic wastes and forest residues [7–10]. In practice, its successful use depends mostly on the influence of process parameters involved during the fermentation process. Process parameters that influence the biogas yield during anaerobic digestion process are solid concentration, pH, temperature, C/N ratio, pretreatment, etc. [5,9]. In order to maximize the production of biogas, parametric optimization of biogas process is essential. In conventional approach, the optimization can be done by altering one parameter at a time, while maintaining the values of other parameters constant thereby the impact of an individual parameter can be understood. This approach needs more number of experiments and consumes lot of time. Also, it is costly and determining mutual interactions between the parameters are not possible [11].

Nowadays, various optimization techniques like Taguchi method, Response Surface Method (RSM), Artificial Neural Network (ANN) and Genetic Algorithm (GA) are widely used in optimizing the process parameters [12]. Many researchers have successfully applied these techniques in physical, chemical and biological sciences [13–17]. These techniques not only help to save the operating cost and time, but are also efficient and can be reproducible. Design of experiment (DoE) based approach is used to provide reliable and accurate information. The main purpose for choosing Taguchi method is, this allows examination of several parameters at the same time with few experimental conditions

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**Nomenclature**

| | | | |
|---|---|---|---|
| TS | total solids | GRG | grey relational grade |
| VS | volatile solids | ANOVA | analysis of variance |
| COD | chemical oxygen demand | DoE | design of experiments |
| VSRE | volatile solid removal efficiency | DoF | degree of freedom |
| CODRE | chemical oxygen demand removal efficiency | SS | sum of squares |
| CD | co-digestion | MS | mean square |
| NT | no treatment | C | carbon |
| AC | autoclave | N | nitrogen |
| MW | microwave | C/N ratio | carbon to nitrogen ratio |
| US | ultrasonication | S/N ratio | signal to noise ratio |
| GRA | grey relational analysis | SC | solid concentration |
| GRC | grey relational coefficient | | |

and provides quantitative information. Selecting the parameters and their values rely on the researchers skill from the pilot experiments conducted, which makes the Taguchi method most reliable. Design in Taguchi's technique makes use of Signal-to-Noise (S/N) ratio, a statistical measure to analyze an output for the given combination of input parameters. Three standard categories of S/N ratios are: "larger the better", "smaller the better" and "nominal the best". Based on the output parameter value desired, S/N ratios are calculated from the category chosen and for determining the optimum condition of each response, maximum values of S/N ratios are used [18,19]. However, the limitation of traditional Taguchi method is, it can be applied to solve single objective problems only and cannot be used for multi-objective optimization problems. To overcome this problem and to optimize multiple objectives, Taguchi method is combined with Grey relational analysis (GRA) to optimize multiple characteristics.

In grey relational analysis, the term 'grey' means partially available information, which lies between the 'black' (symbols having no information) and 'white' (symbols providing full information). For problems with meager and incomplete information and uncertainty, this method is suitable. This technique is suitable for solving multiple objectives. This method transforms multiple responses into a single grey relational grade, from which the optimal process parameters are selected by developing the response table [20]. Several research works reported, shows that combining Taguchi's technique with GRA may be an effective and practical approach towards solving multi-response problems [18,21]. For achieving better performances, it seems that this hybrid method can be useful, and also for determining the effects of individual parameters.

In the present work, optimization of process parameters for biogas production was carried out using Taguchi-Grey relational analysis. Experiments were performed for an orthogonal layout of $L_{16}$ with different parameters (Solid concentration, pH, temperature, C/N ratio and pretreatment types) each at four different levels. For analyzing the experimental results, Minitab16 was used. The main effect of individual parameters and interaction effect between two individual parameters were also studied.

## 2. Materials and methods

Production of biogas from food waste by anaerobic digestion was performed using lab scale batch reactors. The process parameters which influencing the biogas yield, volatile solid removal efficiency and COD removal efficiency are identified for experimentation and subsequently the procedure of research methodology has been designed. Based on designs from Taguchi's DoE, experiments were performed [22]. By applying the hybrid technique of Taguchi-GRA and statistical tool ANOVA, results are analyzed. Development of empirical models for output response prediction is carried out with multiple regression models. The methodologies applied in this present work are given in the flow chart and are shown in Fig. 1.

### 2.1. Feedstock used

Food waste is a highly desirable substrate for anaerobic digestion with regards to its higher biodegradability and biogas/methane yield. This contains a substantially large amount of organic matter, which can be digested anaerobically to produce biogas. Also, the nutrient content analysis showed that the food waste contained well balanced nutrients for anaerobic microorganisms [23]. Food waste used for this experiment was taken from hostel mess of National Institute of Technology Calicut, India. The collected food waste was crushed with the help of kitchen blender and stored at 5 °C until use. Water was added to obtain the desired solid concentration (7.5, 10, 12.5 and 15% of total solids) and 1 N sodium bicarbonate solution was used to maintain the desired pH value (6)–(9). Poultry manure collected from Regional Poultry Farm, Chathamangalam, Calicut was added with food waste in order to vary the C/N ratio before feeding into the digester. Four different substrates were prepared by co-digesting 10, 20, 30 and 40% of poultry manure with 90, 80, 70 and 60% of food waste respectively. The C/N ratios of food waste, poultry manure and the co-digested substrates were given in Table 1. Cow dung was used as an inoculum for starting the experiments. Substrate to inoculum ratio was taken as 9:1 as suggested by Sivakumar et al. [24].

### 2.2. Analytical methods

The total solids, volatile solids, fixed solids and chemical oxygen demand of the substrate and digestate were determined as per the standard method [25]. pH of the substrate and digestate was determined using pH meter (pH-201, Lutron Electronic Enterprise, Taiwan). The elemental composition was determined using elemental analyzer (Elementar Vario EL III, ELEMENTAR Analysensysteme, Germany). The composition of methane and carbon dioxide in the biogas were measured using infrared gas analyzers (PIR-89, Technovation Analytical Instruments, India).

### 2.3. Experimental setup

Laboratory scale batch anaerobic digesters were used to carry out the experiments. Each reactor was made of glass vessel (2000 ml) equipped with water bath for temperature control and magnetic stirrer for agitation. The schematic view of anaerobic reactor used for the experimentation is shown in Fig. 2. The biogas

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