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# Evaluation of Different Compositions of Organic Fuel for Biogas Production Using Fuzzy Modeling

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***Authors' contributions***

*This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.*

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## ABSTRACT

Production of biogas is dependent on composition of organic fuel. Evaluation of different compositions of organic fuel for biogas production using fuzzy modeling was conducted. Eleven variants of composition were determined. For evaluation of these variants an existing method based on the use of fuzzy indicator models was utilized. Results of computation for variable "The electrical energy yield" indicated that composition of organic fuel (variant 11) was the best alternative.

*Keywords: Biogas; organic fuel; fuzzy indicator.*

## 1. INTRODUCTION

Production of biogas is based on the treatment of organic wastes using anaerobic digestion. Anaerobic digestion is a biological process that involves the bacteria decomposition of organic compounds in organic waste material to methane, carbon dioxide and simpler organic compounds [1]. Various wastes have been utilized for biogas production and they include amongst others animal and industrial wastes [2,3], food processing wastes [4], and vegetable wastes [1,5].

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Vegetable wastes, due to high biodegradability nature [6] and high moisture content (75 – 90%) seemed to be a good substrate for bio-energy recovery through anaerobic digestion process [5].

Many researchers studied anaerobic digestion of vegetable. A laboratory study [1] was carried out on anaerobic digestion of vegetable wastes (brinjal, cabbage, carrot, ladies finger) & flowers (jasmine, sunset flower, Roselle, African wattle, Nile tulip flower, silk tree mimosa). The substrate concentrations are varied such as 5, 7 and 10%. The Results of laboratory study showed that flowers had given higher yield of biogas. The average biogas production potential of withered flowers was equal to 16.69 g/kg for 4.5 days [1].

Vegetable wastes (banana stem, cabbage and ladies finger) were an-aerobically digested in a fed-batch laboratory scale reactor at mesophilic conditions [5]. The average methane content in the biogas was 65%.

The waste from various biodegradable sources could be utilized as a feed material for the gas production. Bolzonella et al. [2] studied anaerobic digestion of mechanically sorted organic fraction of municipal solid wastes. Comparative studies of biogas production using various substrates were carried out [7]. Currently special attention is given the humic acids substrates [8-10], which is highly ecologically clean natural coenzymes for biogas plants.

Production of biogas is dependent on composition of organic fuel. Evaluation of different compositions of organic fuel for biogas production can be carried out using fuzzy modeling [11–17].

The aim of this study was assessment of different compositions of organic fuel using method based on combination of fuzzy indicator models.

## 2. MATERIALS AND METHODS

### 2.1 Experimental Data

The data utilized in this manuscript were obtained from an experiment which was conducted on an industrial biogas plant in Saxony, Germany, in 2008 and 2009, at the initiative of the German company EuroConcord Corporation GmBH, Berlin.

The biogas plant is based on the classic "wet" method of recycling organic waste. It consists three parts: hydrolyser, the main reactor and gasholder.

The daily rate of the organic waste load was equal to 80 $kg^3$ and the nutrient substrate load was equal to 20 $kg^3$. Monitoring the main parameters was realized on the basis of industrial controllers of Siemens CPU 315-DP2. The fragments of data are shown in Table 1.

### 2.2 Tool for Evaluation of Different Compositions of Organic Fuel for Biogas Production

For evaluation of different compositions of organic fuel for biogas production we used method developed by Kurtener et al. [11–14, 17], and based on combination of fuzzy indicator models reflected numerical experimental data, and quality estimations of these data. This method includes two parts: modeling of Individual fuzzy indicator (IFI) and quality verification of the initial information.

#### 2.2.1 Modeling of Individual fuzzy indicator

Individual fuzzy indicator is defined as a number in the range from 0 to 1, which reflects an expert concept and modelled by an appropriate membership function. The choice of a membership function is somewhat arbitrary, but should mirror the subjective expert concept. Recently a methodological basis for defining membership functions was developed [11–17] and was utilized in this manuscript.

Evaluation of different compositions of organic fuel for biogas production was carried out using two variables: a) the electrical energy yield, and b) hydrogen sulphide.

#### 2.2.2 Model of IFI for "The electrical energy yield”

According to experimental data, the value of variable "the electrical energy yield" is equal 5,200 kWh or more and can be equated with a score of 100 points. If the value of variable "the electrical energy yield" is less than 2,700 kWh, then the score should be reduced to 0 point. For example, 8/20/2008 variable "the electrical energy yield" is equal to 1,700 kWh. In this case the value of IFI of this variable is less than 2,700 kWh and IFI = 0.

**Table 1. Fragment of experimental data of 2009**

| Date | Volume of composition, $m^3$ | Co-substrate | | | | The electrical energy yield, kWh | Temperature of hydrolysis, °C | Temperature of air headspace, °C | Gas values | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Poultry manure, $kg^3$ | Corn silage, $kg^3$ | Silage, $kg^3$ | Cereals, $kg^3$ | | | | $CH_4$, % | $H_2S$, ppm | $O_2$, % |
| 1/10/2009 | 60 | 8.0 | 6.0 | 0.0 | 1.0 | 4,600 | 23.4 | 39.9 | 60 | 783 | 0.0 |
| 1/11/2009 | 60 | 8.0 | 6.0 | 0.0 | 1.0 | 4,700 | 23.5 | 40.0 | 61 | 703 | 0.0 |
| 1/12/2009 | 60 | 8.0 | 6.0 | 0.0 | 1.0 | 4,800 | 23.6 | 40.0 | 61 | 667 | 0.0 |
| 1/18/2009 | 60 | 10.0 | 6.0 | 0.0 | 1.0 | 3,800 | 25.7 | 40.0 | 61 | 314 | 0.1 |
| 1/19/2009 | 60 | 10.0 | 6.0 | 0.0 | 1.0 | 3,400 | 25.1 | 40.0 | 61 | 248 | 0.0 |
| 1/20/2009 | 60 | 10.0 | 6.0 | 0.0 | 1.0 | 3,400 | 24.8 | 40.0 | 62 | 227 | 0.1 |
| 1/22/2009 | 60 | 12.0 | 6.0 | 0.0 | 1.0 | 1,800 | 25.3 | 39.6 | 62 | 174 | 0.1 |
| 1/23/2009 | 60 | 12.0 | 6.0 | 0.0 | 1.0 | 4,600 | 25.5 | 39.9 | 62 | 202 | 0.1 |
| 1/24/2009 | 60 | 12.0 | 6.0 | 0.0 | 2.0 | 3,300 | 25.2 | 39.7 | 63 | 245 | 0.1 |
| 3/18/2009 | 60 | 12.0 | 6.0 | 0.0 | 2.0 | 3,200 | 26.2 | 40.4 | 61 | 91 | 0.1 |
| 3/19/2009 | 60 | 12.0 | 6.0 | 0.0 | 1.5 | 3,500 | 26.0 | 40.0 | 60 | 113 | 0.1 |
| 3/20/2009 | 60 | 12.0 | 6.0 | 0.0 | 1.5 | 3,300 | 25.6 | 40.0 | 61 | 154 | 0.1 |
| 4/3/2009 | 60 | 12.0 | 6.0 | 0.0 | 1.5 | 4,000 | 27.0 | 40.0 | 61 | 212 | 0.1 |
| 4/4/2009 | 60 | 12.0 | 6.0 | 0.0 | 1.5 | 3,800 | 27.0 | 40.1 | 61 | 218 | 0.0 |
| 4/5/2009 | 60 | 12.0 | 6.0 | 0.0 | 1.5 | 2,800 | 27.0 | 40.0 | 61 | 210 | 0.1 |
| 4/6/2009 | 60 | 12.0 | 6.0 | 0.0 | 1.5 | 3,500 | 27.2 | 39.9 | 61 | 218 | 0.1 |
| 4/7/2009 | 60 | 12.0 | 6.0 | 0.0 | 1.5 | 3,600 | 27.4 | 40.0 | 61 | 238 | 0.1 |
| 4/8/2009 | 60 | 12.0 | 6.0 | 0.0 | 1.5 | 3,800 | 27.5 | 39.9 | 61 | 221 | 0.1 |
| 4/9/2009 | 60 | 12.0 | 6.0 | 0.0 | 1.5 | 4,100 | 27.3 | 40.0 | 60 | 202 | 0.1 |
| 4/10/2009 | 60 | 12.0 | 6.0 | 0.0 | 1.5 | 4,100 | 27.5 | 40.0 | 60 | 196 | 0.1 |
| 4/11/2009 | 60 | 12.0 | 6.0 | 0.0 | 1.5 | 4,100 | 27.3 | 40.0 | 61 | 217 | 0.1 |
| 4/21/2009 | 60 | 12.0 | 6.0 | 0.0 | 1.5 | 4,100 | 27.0 | 40.0 | 60 | 201 | 0.1 |
| 4/22/2009 | 60 | 0.0 | 18.0 | 0.0 | 1.5 | 4,100 | 27.5 | 40.0 | 61 | 174 | 0.1 |
| 4/23/2009 | 60 | 0.0 | 10.0 | 0.0 | 1.5 | 4,100 | 26.5 | 40.1 | 59 | 154 | 0.1 |
| 4/24/2009 | 60 | 0.0 | 14.0 | 0.0 | 1.5 | 4,000 | 26.5 | 40.0 | 59 | 105 | 0.2 |
| 4/25/2009 | 60 | 8.0 | 8.0 | 0.0 | 1.5 | 4,200 | 26.5 | 40.0 | 58 | 84 | 0.2 |
| 4/26/2009 | 60 | 8.0 | 8.0 | 0.0 | 1.5 | 3,400 | 27.2 | 40.1 | 57 | 97 | 0.2 |
| 4/27/2009 | 60 | 8.0 | 8.0 | 0.0 | 1.5 | 3,100 | 27.2 | 40.0 | 57 | 99 | 0.2 |
| 4/28/2009 | 60 | 8.0 | 8.0 | 0.0 | 1.5 | 4,600 | 27.4 | 40.0 | 57 | 107 | 0.2 |

| Date | Volume of composition, $m^3$ | Co-substrate | | | | The electrical energy yield, kWh | Temperature of hydrolysis, °C | Temperature of air headspace, °C | Gas values | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Poultry manure, $kg^3$ | Corn silage, $kg^3$ | Silage, $kg^3$ | Cereals, $kg^3$ | | | | $CH_4$,% | $H_2S$, ppm | $O_2$, % |
| 4/29/2009 | 60 | 10.0 | 8.0 | 0.0 | 1.5 | 2,700 | 27.4 | 39.9 | 58 | 96 | 0.2 |
| 5/5/2009 | 60 | 10.0 | 8.0 | 0.0 | 1.5 | 4,200 | 27.8 | 40.1 | 61 | 61 | 0.1 |
| 5/6/2009 | 60 | 10.0 | 8.0 | 0.0 | 1.5 | 4,500 | 27.6 | 40.0 | 61 | 83 | 0.1 |
| 5/7/2009 | 60 | 7.0 | 8.0 | 0.0 | 1.5 | 4,400 | 27.3 | 40.0 | 61 | 87 | 0.1 |
| 5/8/2009 | 60 | 13.0 | 8.0 | 0.0 | 1.5 | 4,600 | 27.8 | 40.0 | 61 | 87 | 0.1 |
| 5/9/2009 | 60 | 10.0 | 8.0 | 0.0 | 1.5 | 4,400 | 27.5 | 40.1 | 60 | 112 | 0.2 |
| 5/10/2009 | 60 | 10.0 | 8.0 | 0.0 | 1.5 | 5,200 | 27.8 | 39.9 | 60 | 123 | 0.2 |
| 5/11/2009 | 60 | 10.0 | 8.0 | 0.0 | 1.5 | 3,700 | 27.4 | 40.0 | 61 | 126 | 0.1 |
| 5/12/2009 | 60 | 10.0 | 8.0 | 0.0 | 1.5 | 4,600 | 27.5 | 40.1 | 60 | 128 | 0.2 |
| 5/13/2009 | 60 | 10.0 | 8.0 | 0.0 | 1.5 | 3,800 | 27.2 | 40.0 | 60 | 169 | 0.2 |
| 5/14/2009 | 60 | 10.0 | 8.0 | 0.0 | 1.5 | 4,200 | 27.6 | 39.9 | 59 | 164 | 0.1 |

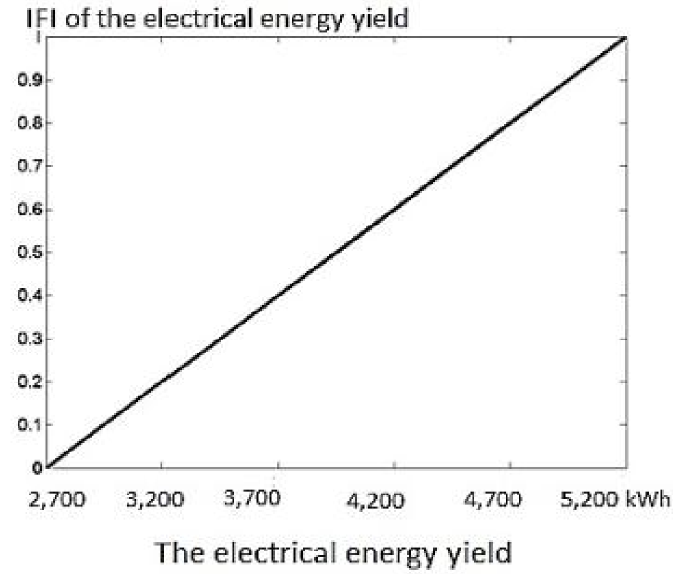


**Fig. 1. The graphical presentation of simple fuzzy indicators "IFI of the electrical energy yield"**

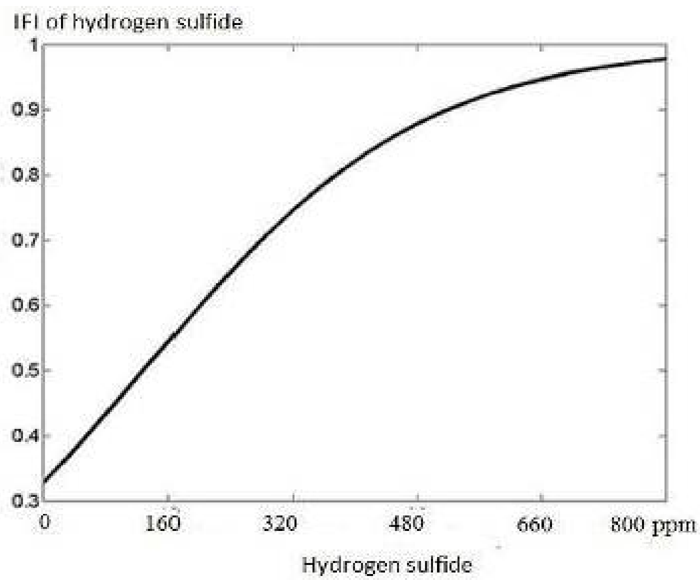


**Fig. 2. The graphical presentation of simple fuzzy indicators "IFI of hydrogen sulfide"**

Taking into account this information, an individual fuzzy indicators (IFI) was built for variable "the electrical energy yield" using the linear built-in membership function (Fig. 1).

#### 2.2.3 Model of IFI on variable "(Hydrogen sulphide)"

According to experimental data, the value of variable "Hydrogen sulphide" is equal 783 ppm or more and can be equated with a score of 100 points. If the value of variable "Hydrogen sulfide" is less than 61 ppm, then the score should be reduced to 0 point. Taking into account this information, an individual fuzzy indicators (IFI) was built for variable "Hydrogen sulphide" using the S-shaped built-in membership function (Fig. 2).

#### 2.2.4 Quality verification of the initial information

It is well known that experimental data have uncertainties, which range from measurement error to mistakes of experimenters. For dealing with randomness and uncertainties it was suggested to make quality verification of the initial information using expert panel.

Quality of data is estimated, usually in a scale or in dimensionless units. In method developed by Kurtener et al. [11–14,17], quality of data is estimated using Quality Indicater (QI). QI ranges from 0 to 1.

#### 2.2.5 Definition of combined fuzzy indicators

The combined fuzzy indicators (CFI) was defined as combination of Individual Fuzzy Indicator (IFI) and Quality Indicator (QI). In particular, CFI is defined as Equation (1):

$$CFI_x = IFI_x \prod QI_i$$

where ∏ is the product operator for the product of a sequence of $QI_i$, $IFI_x$ is IFI of *x*-variable, $QI_i$ is estimation of *i* expert.

#### 2.2.6 Computation

Computation was conducted utilizing the author's program, which included several scripts written on MATLAB [18].

## 3. RESULTS AND DISCUSSION

Using the experimental data we define variants of composition of organic fuel (Table 2). Computation for variable "The electrical energy yield" was carried out using method described above (fragment of computational data is given in Table 3). Output of the computation showed that composition of organic fuel (variant 11) was the best alternative. Variant 8 was on second position.

Computation for variable "Hydrogen sulfide" showed that of composition of organic fuel (variant 11) was the best alternative. Variant 10 was on second position.

**Table 2. Composition of organic fuel according to data of 2008**

| Variant of composition | Poultry manure, $kg^3$ | Corn silage, $kg^3$ | Silage, $kg^3$ | Cereals, $kg^3$ | Volume of organic fuel, $m^3$ |
|---|---|---|---|---|---|
| 1 | 4.0 | 3.0 | 0.0 | 0.3 | 35 |
| 2 | 6.0 | 4.0 | 0.0 | 0.5 | 45 |
| 3 | 8.0 | 6.0 | 0.0 | 1.0 | 60 |
| 4 | 10.0 | 0.0 | 8.0 | 2.0 | 80 |
| 5 | 10.0 | 0.0 | 8.0 | 1.5 | 80 |
| 6 | 12.0 | 0.0 | 5.5 | 1.5 | 80 |
| 8 | 12.0 | 8.5 | 0.0 | 0.0 | 80 |
| 9 | 12.0 | 8.5 | 2.0 | 0.0 | 80 |
| 10 | 12.0 | 8.5 | 0.0 | 1.0 | 80 |
| 11 | 12.0 | 8.5 | 2.0 | 1.0 | 80 |

**Table 3. Fragment of computational data for variant of composition 4**

| The electrical energy yield, kWh | IFI of the electrical energy yield | $QI_i$ | $CFI_x$ of the electrical energy yield |
|---|---|---|---|
| 5,000 | 0.571 | 1 | 0.571 |
| 5,000 | 0.571 | 1 | 0.571 |
| 5,000 | 0.571 | 1 | 0.571 |
| 5,400 | 0.714 | 1 | 0.714 |
| 3,400 | 0 | 1 | 0 |
| 6,200 | 1 | 1 | 1 |
| 5,500 | 0.750 | 1 | 0.750 |
| 5,900 | 0.892 | 1 | 0.892 |
| 4,600 | 0.428 | 1 | 0.428 |
| 3,500 | 0.035 | 1 | 0.035 |

## 4. CONCLUSION

Production of biogas is dependent on composition of organic fuel.

Evaluation of different compositions of organic fuel for biogas production using fuzzy modeling was conducted. Eleven variants of composition were determined. For evaluation of these variants an existing method based on the use of fuzzy indicator models [11–14,17] was utilized. Results of computation for variable "The electrical energy yield "indicated that composition of organic fuel (variant 11) was the best alternative. Variant 8 was on second position.

Also, results of computation for variable "Hydrogen sulfide" indicated that of composition of organic fuel (variant 11) was the best alternative. Variant 10 was on second position.

It was found that this tool would be advantageous for application in future studies for elaboration of problem-oriented research, especially under the growing uncertainty of traditional fuel and grain prices.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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