DESIGNING A FUZZY LOGIC BASED CONTROL SYSTEM FOR EFFICIENT ENERGY GENERATION FROM KITCHEN WASTE

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ABSTRACT

This paper examines the mesophilic anaerobic digestion of kitchen waste at a controlled temperature of 40 °C, using solar energy. The temperature control is proposed to be achieved by controlling the mass flow rate of hot water through a heat exchanger in the digester tank. A simulation study of performance of a digester system coupled with a solar collector and a storage tank, under time varying atmospheric conditions, for the month of March in Delhi is presented. The digester will generate bio gas which is a useful source of renewable energy and the residue from the digester can be used as manure. The process also provides an effective method of solid bio-waste management which is one of the serious civic problems in residential areas. In this simulation study, the sizing of the various components is based on the rates of heat and mass transfer. A fuzzy logic controller is developed and its performance is compared with the results obtained from computer simulation

Keywords: *Fuzzy Logic Controller, Renewable Energy, Kitchen Waste, Solar Thermal Collector.*

INTRODUCTION

The chemical energy of the organic matter in a kitchen waste is a useful source of renewable energy. The waste contains complex organic compounds like carbohydrates, proteins and cellulose which can be converted into simple compounds such as methane, carbon dioxide and other constituents through a series of biochemical reactions. A popular method to achieve this conversion is known as anaerobic digestion (AD) [1]. The mixture of methane and carbon dioxide (bio-gas) can be used as a fuel and the residue (digestate) can be used as a manure.

The anaerobic conversion process is accomplished in absence of oxygen, generally in four stages: pretreatment, digestion, gas up-gradation and digestate treatment [2]. The pretreatment stage consists of breaking the waste material into smaller pieces, removing the unwanted objects (e.g. plastics, glass), adding water and mixing. A suitable catalyst or a seeding material is added and the mixture undergoes the digestion process in absence of Oxygen (AD), in three main steps: Hydrolysis, Acetogenisis and methanogenisis [3]. During hydrolysis, the fermentative bacteria converts the insoluble complex organic compounds into fatty acids and amino acids. Acetogenic bacteria produces simpler acids such as acetic acid, butylic acid, propionic acid, ethanol, carbon dioxide and hydrogen. Finally, reduction of CO_2 with H_2 generating CH_4 is carried out by methanogenic bacteria. A schematic diagram of

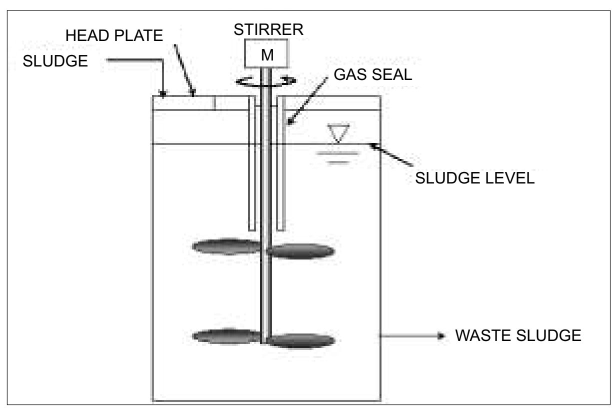

Figure 1: Schematic Diagram of a Bio digester

a typical bio-digester is given below in figure 1. In a typical AD process, the following variables influence the performance of the system [1]:

1. Solid Contents: 10-40%
2. Temperature
   a) Mesophilic: 20-45 °C
   b) Thermophilic: 50-65°C

3. Retention Time
a) Mesophilic: 15-30 days
b) Thermophilic: 12-14days

4. pH: 6.4 to 7.2
5. C/N ratio: 20 -30

1.1 Using Fuzzy Logic for Temperature Control

The concept of fuzzy logic was introduced by Lofti A. Zadeh in 1964 to provide a cost effective solution to real world problems involving uncertainty and vagueness. In 1974, Assilian and E. Mamdani developed the first fuzzy logic controller for a nonlinear multidimensional plant. They showed that the fuzzy control rules can get automatically tuned by fuzzy linguistic adaptive strategies. Thereafter, industrial application of fuzzy controller became very popular all over the world and several software and hardware tools were developed to implement fuzzy logic applications. Fuzzy logic toolbox for MATLAB was introduced in 1994.

Many researchers such as Yunseop Kim [4] have used the concept of fuzzy logic for temperature control. Temperature is not explicitly defined. There is some vagueness or uncertainty when one says, "This object is hot " In a fuzzy system, the degrees of hotness, for example 'cold', 'not so cold', 'warm' 'not so hot' and 'hot' may be represented by a set of numbers between 0 and 1, e.g. 0, 0.2, 0.4, 0.6, 0.8, 1.0 etc. The fuzzy temperature controller may be described by a knowledge based algorithm. Ravi et al [5] developed an algorithm based Fuzzy Logic Controller for temperature control. They have reported that the proposed controller has good set point tracking and disturbances rejection properties. Zhiqiang Gao et al [6] developed a "Stable Self-Tuning Fuzzy Logic Control System for Industrial Temperature Regulation". Mitra Mirhosseini et al [7] have also designed a Fuzzy Logic Controller for Industrial Temperature Regulation. These authors have reported that the results obtained from the FLC are comparable with those obtained from the conventional PID controllers. For optimal fermentation in a Brewery, the control of temperature plays a dominant role. Philip Babatunde Osofisan [8] has developed a Fuzzy Logic Controller and simulated the process using MATLAB 5.0 Fuzzy Logic Tool Box.

2. The Present Study

Various studies [9, 10] conducted all over the world have shown that the process of anaerobic digestion of food waste is significantly improved when the temperature is maintained at about 40°C inside the digester. However, this requires consumption of thermal energy. In this paper, the possibility of utilizing solar energy for heating the biomaterial in digester has been examined through a case study. The bio digester will be installed near the college canteen of BVCOE, New Delhi.
The system will consist of a solar collector, a hot water storage tank and a digester tank as shown in Fig. 2. The temperature of the digester will be maintained at 40°C by means of a heat exchanger which will receive hot water from the hot water storage tank (HST) to be maintained at 55°C by the solar collector to be installed at the roof of the canteen building. The surplus hot water from the HST will be utilized in the kitchen itself. The case study has been carried out on the basis of the weather data for the month of March in Delhi, taken from the Hand book by S. Mani .

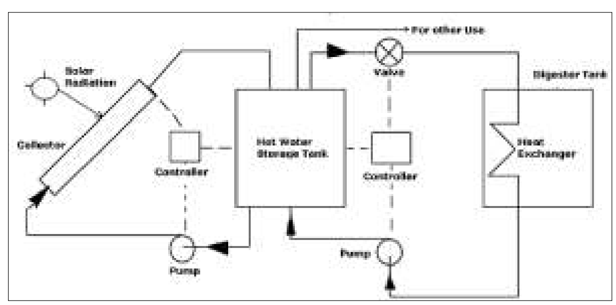

Figure 2: A Bio Digester Coupled with a Solar Water Heater System

2.1 Fuzzy Logic Controller

In the present study, the optimal temperature control for process in the proposed bio digester will be achieved by using a FLC.The FLC will have 2 input variables namely, solar radiation intensity and the ambient air temperature. The out put variable is the mass flow rate of hot water entering the digester. The enthalpy rate of the incoming hot water will balance the enthalpy rate of the returning and also the heat loss to the surroundings.

3. Modeling of the System

3.1 Solar Collector

The energy rate (q_c) absorbed by a typical flat plat solar collector is given by the following equation:

$$q_c = A_c F_r (I\,\alpha\tau - U(t_i - t_a)) \qquad (1)$$

where

A_c = area of the collector, m^2
F_r = correction factor, dimensionless
I = Intensity of solar radiation, W/m^2
$\alpha\tau$ = is the product of absorptivity and transmittance of collector glass
U = Overall heat transfer coefficient, W/ K
t_i and t_a are the temperatures of the incoming fluid and ambient air respectively.

In the present simulation study hourly values of the collector energy rate have been computed taking A_c = 6 m^2, F_r = 0.9, $\alpha\tau$ = 0.8, U= 1.5 W/ m^2. K, and t_i = 50°C. The hourly values of weather data (I and t_a) for the month of March in Delhi have been taken from reference [7]. The results are plotted in Fig.3.

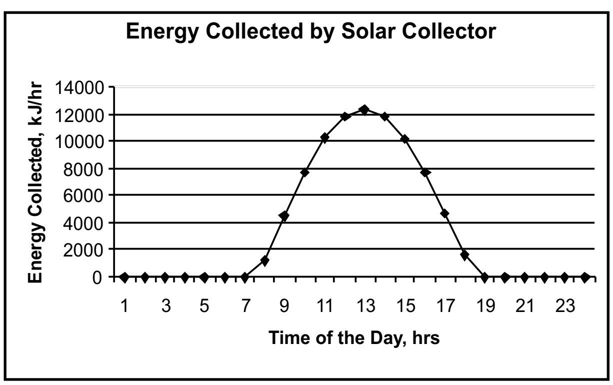

Fig.3: Hourly Values of Thermal Energy Collected by the Solar Collector

The Digester Tank

The digester tank has been modeled using lumped thermal capacitance and overall heat transfer concept:

$$CAP\,(dT_{in}/dt) = C_{min}(T_{ex} - T_{in}) - UA(T_{in} - T_a) \qquad (2)$$

where

CAP = Effective thermal capacitance of the digester tank including its contents
T_{in} = Inside temperature
C_{min} = Capacitance rate of exchanger fluid (hot water)
T_{ex} = Temperature of exchanger fluid (hot water)
UA = Overall heat transfer coefficient
T_a = Ambient air temperature

The digester is designed to handle 1 m^3 of bio mass with an average specific heat of 4.2 kJ/kg.K, and UA= 40 kJ/ °C.

Hourly values of thermal energy required to maintain a constant temperature at 40°C , for time varying ambient air conditions, have been determined by simulation and required flow rate of hot water has been computed by heat balance. The results are plotted in Fig.4

3.2 The Hot Water Storage Tank

The hot water tank is designed to maintain 50°C. During the sunshine hours, the storage tank stores surplus amount of hot water and supplies it to the digester continuously even when sun shine is not available. Heat balance is maintained by controlling flow rates of incoming and outgoing streams as well as their temperature.

Hourly values of mass and heat transfer rates have been compute by simulation and the results

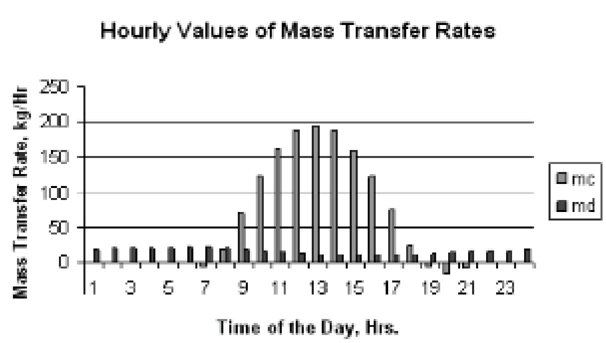

Figure 4: Hourly Values of Mass Transfer Rates of Hot Water from the Solar Collector to Storage Tank (mc) and from Storage Tank to Digester (md)

are plotted in figure 5.

3.3 Controller

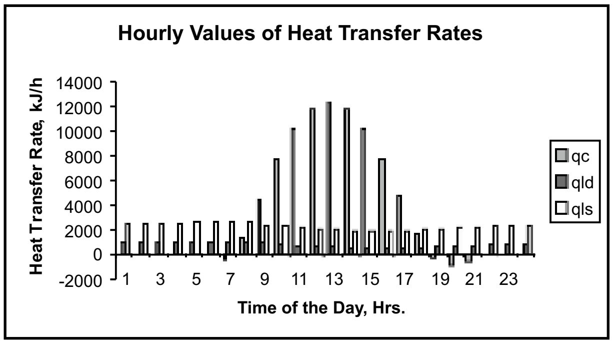

Figure 5: Hourly Values of Heat Transfer Rates from the Solar Collector to Storage Tank (qls) and from Storage Tank to Digester (qld). The Rates of Total Energy Collected (Qc) by the Solar Collector are also Shown

For the present study a FLC is designed to maintain the temperature of the digester at 40°C under the time-varying solar radiation and temperature of the surroundings. The flow rate of hot water from the storage tank to the digester is to be controlled so that the heat balance is maintained and the temperature is kept constant. We define the following variables as the inputs and the out put for the fuzzy controller:

Input 1 =Hourly values intensity of solar radiation incident on the collector, kJ/hr. m^2

Input 2 = Hourly values of mean ambient air temperature in the month of March in Delhi (taken from the weather data) Output = Hourly values of mass flow rate of hot water entering the digester through heat exchanger, kg/hr

The fuzzy controller consists of the following components:

3.3.1 Fuzzification:

The input and out put variables are expressed as fuzzy variables using standard procedure. The inferences are drawn using common experience and the trends of the simulation results mentioned above. The defuzzified crisp output hourly values of mass flow rates of hot water will be used for maintaining the required steady temperature of 40 °C in side the digester tank.

3.3.2 FIS variables

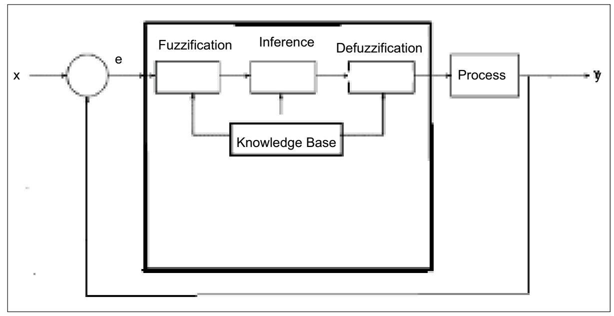

Fig. 6: Block Diagram of the Fuzzy Logic Controller

In this study, the in put and the out put variables used for the fuzzy inference system (FIS) are described below:

FIS Variables:

Input 1: Intensity of solar radiation (I), kJ/hr. m^2 . The hourly values of I in the month of March in Delhi vary from 0 to 12000 kJ hr. m^2.These values are normalized in the range of 0 to 1.

Input 2: Ambient air temperature (T), °C . The mean hourly values of T in the month of March in Delhi vary from 17°C to 29 °C .These values are normalized in the range of 0 to 1.

Output: Mass flow rate of hot water to be supplied to the digester through the heat exchanger, kg/hr (M). The predicted hourly values of M for the month of March in Delhi vary from 0 to 13.5 kg/hr . These values are normalized in the range of 0 to 1.

3.3.3 Fuzzy IF Then Rules

The fuzzy rules adopted for the present study are of the following type:

R_i: If intensity of solar radiation is high And If ambient temperature is high Then the required mass flow rate of hot water entering the digester is low.

R_j: If intensity of solar radiation is medium And If ambient temperature is medium Then the required mass flow rate of hot water entering the digester is medium.

R_k : If intensity of solar radiation is low And If ambient temperature is low Then the required mass flow rate of hot water entering the digester is high.

We have used MATLAB-7.0.1 tool box for designing the FLC parameters. The membership Function Editor shown in Figure 7 depicts the input variables and the corresponding fuzzy rule base is described in Figure 8. The antecedents for these rules have been derived from common experience and the simulation results of heat balance equations explained in section 3 above. Figure 9 shows the inputs and the corresponding out put on a 3 dimensional surface produced by the MATLAB tool box.

4. CONCLUSIONS

In this simulation study, bio-digestion of kitchen

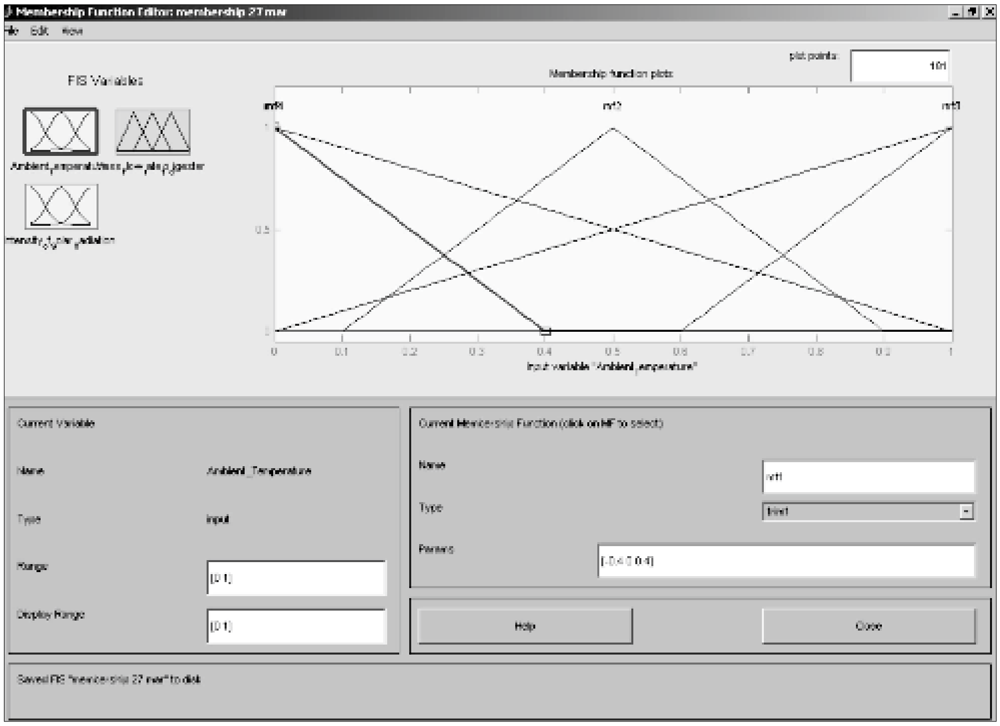

Fig. 7: Membership Functions of Ambient Temperature and Solar Intensity as inputs with Hot water Flow Rate as the output.

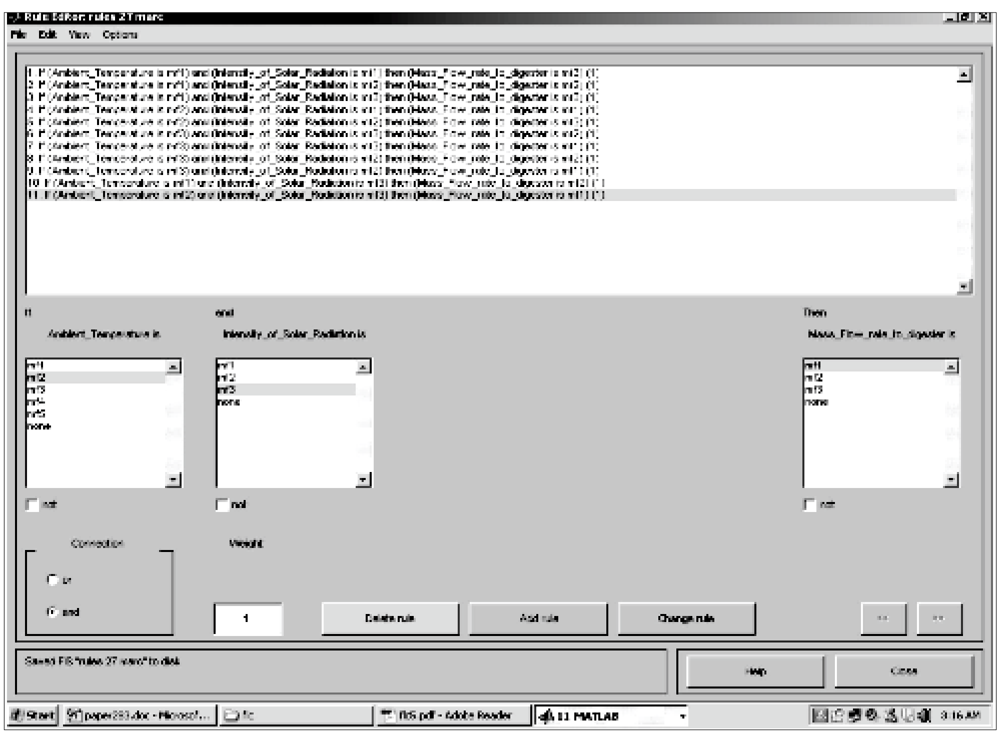

Fig.8: Fuzzy Rule Base for the System

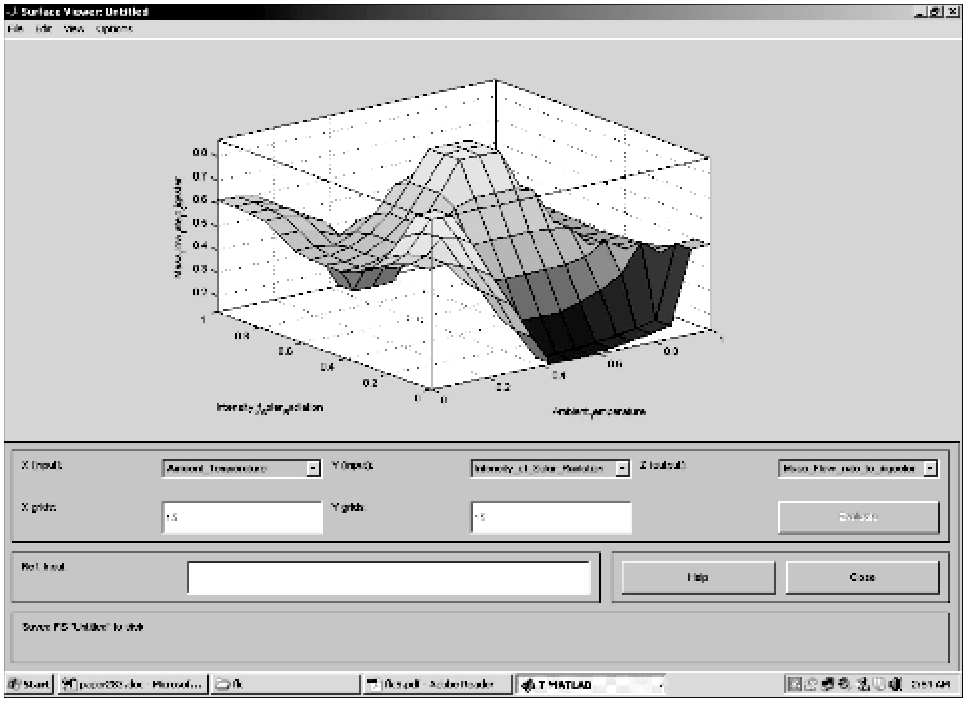

Fig 9: Fuzzy Surface Representing the Inputs & Outputs.

waste for production of methane at a steady temperature of 40°C has been considered. It is estimated that about 250 kg of CH_4 will be produced from one cubic meter of the waste material in a digester tank of 1.1 m^3 capacity, in a time period of approximately 15 days (retention time) under the experimental conditions described in this paper. The temperature inside the digester tank can be maintained at 40°C, by means of a heat exchanger through which hot water flows. It is proposed to provide a 6 square meter flat plate solar collector that will collect about 5 MJ/day out of which 1.5 MJ/day will be used by digester and 2.5 MJ/day by the storage tank for heat dissipation to surroundings and the remaining energy of about 1 MJ per day will be available for other use in the month of March in Delhi.

The maintanence of constant temperature in the digester under variable solar intensity and weather conditions is critical. In the present study, we have developed an FLC for controlling hot water flow rates depending on the other variables. It is observed that the values of flow rates computed by FLC are in agreement with the results of the simulation.

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