APPLCATION OF FUZZY LOGIC TO EVALUATE THE OPERATIONAL PHASE OF A SANITARY LANDFILL

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ABSTRACT

Landfill is the most common and cost-effective option for disposing of solid waste on a global scale. A sanitary landfill is a multi-phase ecosystem with physical, chemical, and biological processes. Climate and site-related elements like as temperature, precipitation, waste characteristics, and installed configurations all have an impact on the system (liner, cover, collection systems, and injection systems. Because of the complexities of landfill operations and the unpredictability of solid waste properties, different modeling approaches have been used to describe the system. Conventional method can not be developed for this unpredictable and complex system because it's very hard to separate the individual impacts of its components and correctly identify their behavior. This complex system of landfill can be modeled by approaches based on knowledge such as fuzzy logic. This study shows how fuzzy logic may be used to solve operational challenge in landfill-leachate. A conventional landfill-leachate possesses some difficultly distinguishable and characterizable operational phases. It's important to recognize these phases. A fuzzy logic controller, based on certain quantitative characteristics of the leachate generated and biogas produced, was developed to identify the operational phase of a landfill at a given moment. This will show current operational phase for several value of inputs with specific degree of transition which will help to determine the exact phase of the landfill.

Keywords: *Sanitary landfill, leachate, gas, operational phase, fuzzy logic*

1. INTRODUCTION

World produces solid waste in a large scale due to household and industrial processes. Any waste that cannot be recycled or repurposed must be disposed of, and most of it ends up in a landfill. The term 'landfill' is used therefore to designate a unit action for the final placement of solid waste on land that is conceived and built with the goal of having the least possible environmental effect (Rafizul et al., 2012). Leachate is an important byproduct of landfills (Rafi et al., 2020). Landfill leachates pose a significant threat to the environment (Abdallah et al., 2011). A landfill is a multi-phase environment including physical, chemical, and biological activities. Sanitary landfills go through basic stabilizing phases.

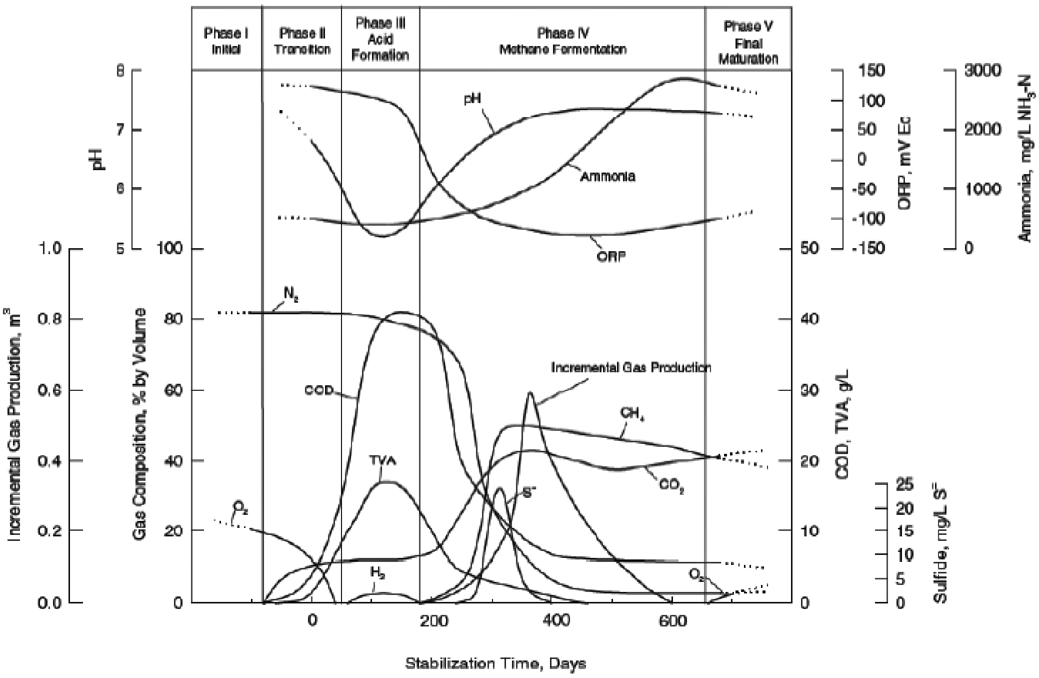

Figure 1: Operational Phases of waste degradation in landfill (Kim et al., 2003)

Figure-1 demonstrates the key characteristics of the waste degradation phases in terms of gas (volume and component) and leachate (quality parameters). The degradation of solid waste can be divided into two main process. The first one is called aerobic phase(phase-1) and the another phase is called anaerobic phase which is comprised of transition (phase-2), acid formation(phase-3), methane generation(phase-4), maturation(phase-5). Increasing the methane generation time is a better strategy to minimize landfill gas's greenhouse gas effect. In the sense of a control instrument, a lysimeter is a simulated version of landfill. The term lysimeter is derived from two Greek words: "Lusis," which indicates "Solution," and "Metron," which indicates "Measure" (Rafizul et al. 2009). Solid waste is usually disposed in an unregulated way into open dumps in underdeveloped countries like Bangladesh, without processes like leachate collecting or treatment facilities. The use of a large number of spatially dependent parameters that cannot be adequately specified in the face of data uncertainty is common in attempts to develop models that represent these complexities. (Zacharof et al., 2004). Furthermore, the variability of waste properties makes determining the individual and simultaneous impact of multiple system factors more difficult. We mostly have information of the inputs and outputs, but the method is so complicated that it is impossible to grasp and apply to create a mathematical model (Garg et al., 2014). Soft computing approaches, notably fuzzy logic, were applied to improve models for system factors such as biogas generation (Abdallah et al., 2009; Zadeh, 2008), and leachate quality (Rendra et al., 2007). The logic on which fuzzy control is built, fuzzy logic, is considerably closer in spirit to human thought and ordinary language than classical logical systems (Lee, 1990). When enough knowledge and information are available, fuzzy logic, which uses linguistic set of rules to capture the understand of experienced human operators, has proven to be a consistent and effective remedy for solving a complex and ill-defined methods like those confronted in landfill operation. This study represents the application of fuzzy logic for evaluation and landfill operation optimization. The Phase Calculator is a fuzzy logic controller (FLC) was developed to identify the present operational phase of landfill. Determining the present operational phase is important since bacterial populations fluctuate considerably over the landfill's lifetime, as do the environment for its optimal growth (Abdallah et al., 2009). The goal of this study is to use FL's modelling capabilities to create a knowledge-based controller which meets the same goal while taking unpredictability into account, and with less and easier-to-determine input variables.

2. METHODOLOGY

A fuzzy logic controller was designed to evaluate the operational phase of constructed sanitary landfill lysimeter at KUET campus. To this attempt, gas composition in terms of CH_4 and CO_2 as well as leachate concentration such as pH, COD, and NH_4-N were considered. Overall methodology of this study are hence discuss in the following sub-headings.

2.1 Selection of Input and Output Variables

This model was constructed based on multiple input and single output. Leachate's pH, percentage of methane gas of the gas produced from the landfill %CH4, chemical oxygen demand COD, percentage of carbon dioxide gas of the gas produced from the landfill %CO2, and ammonia produced in the landfill (NH4-N) are selected as input variables and current phase is selected as output (Figure 2). Data was collected from a constructed sanitary landfill lysimeter at KUET campus.

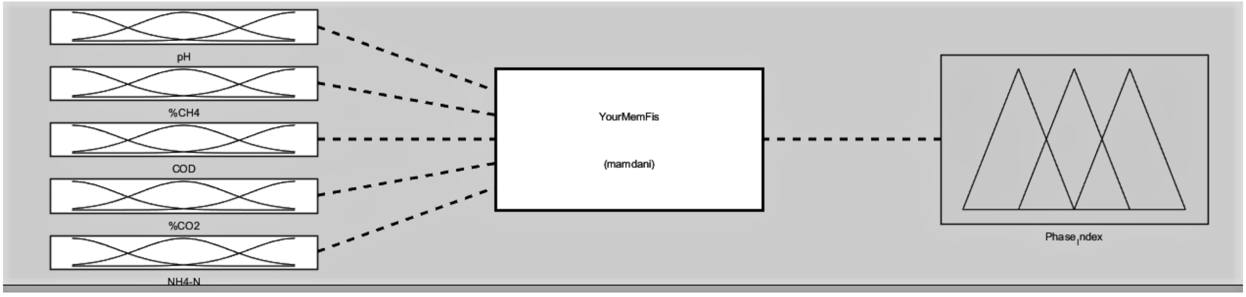

Figure 2: Input and output variables

2.2 Fuzzy Interference System Design

After selecting the input and output variables, the data base is built containing all well defined membership functions with proper linguistic terms called fuzzy set for both input and output variables for necessary data mapped in defined range named as fuzzification (Lee, 1990). The linguistic term is selected based on the collected data from the constructed sanitary landfill lysimeter. A membership function μ_A depends on the degree of truth of a fuzzy set A, which depends on the degree to which it belongs to the set, is expressed by a real integer in the span [0, 1] (Nafis et al., 2000). This is different from conventional numerical sets where an element either belongs or does not belong to a particular set usually called 1 or 0, namely true or false. µBut in fuzzy set, the degree of truth can be known. There are different membership functions having different shapes such as trapezoidal(trapmf), triangular(trimf),gaussian(gaussmf) etc. Triangular and trapezoidal membership functions were used here only where the most probable interval represents the uncertainty in each variable (i.e., the range where the membership degree is equal to 1.0) and the widest possible range (i.e., the range where the membership degree is equal to 0.0) which are shown in Figure 3 and Figure 4. In a trapezoidal fuzzy set, the membership value of an element x may be expressed as follows:

$$\mu_A(x) = \begin{cases} \dfrac{(x-a)}{(b-a)}, a \le x \le b \\ 1, b \le x \le c \\ \dfrac{(x-d)}{(c-d)}, c \le x \le d \\ 0, x \rangle d \;\; or \;\; x \langle a \end{cases}$$

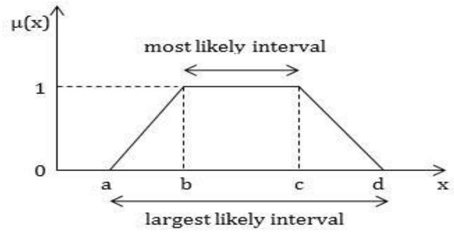

Figure 3: Representation of trapezoidal membership functions

In a triangular fuzzy set, the membership value of an element x may be expressed as follows:

$$\mu_A(x) = \begin{cases} 0 & if\ x \le a \\ \frac{x-a}{b-a} & if\ a \le x \le b \\ \frac{c-x}{c-b} & if\ b \le x \le c \\ 0 & if\ x \ge c \end{cases}$$

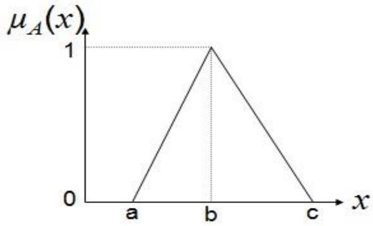

Figure-4: Representation of triangular membership functions

The membership functions (MF) of the fuzzy sets applied as values for every system variable are defined in the database.

Figure 5 illustrates the MFs that have been established for a sample input (pH) which is ranged between 3 to 8. The membership functions for pH are defined as low(L), neutral(N), and high(H) .

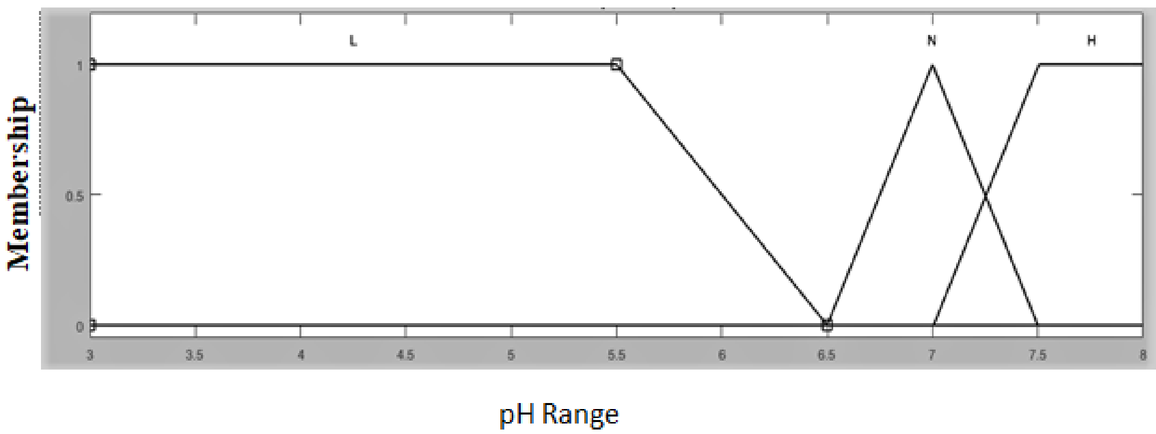

Figure 5: Membership function for pH

The fundamental phases of solid waste decomposition defined the 'Phase Index' variables as aerobic, transition, acid formation and methane generation which is ranged between 1 to 3, defined in Figure 6.

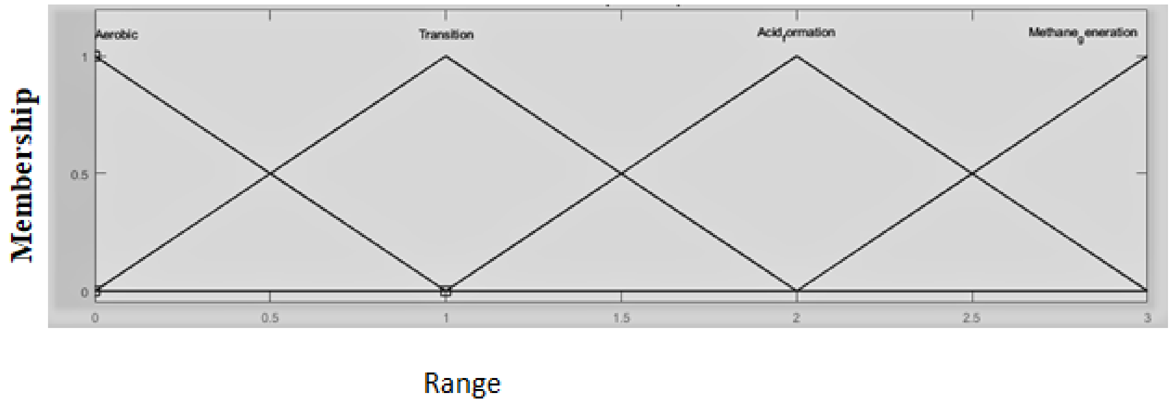

Figure-6: Membership function for Phase index

In the Table1 all the membership functions for every input variables are defined with their linguistic terms.

Table-1: The constructed model's defined fuzzy sets and membership functions for input variables

Variable	Linguistic term for Fuzzy set	Type	Parameters			
			a	***b***	***c***	***d***
pH	Low (L)	Trapezoidal	3	3	5.5	6.5
	Neutral (N)	Triangular	6.5	7	7.5	-
	High (H)	Trapezoidal	7	7.5	8	8
$\%CH_4$	Zero (Z)	Triangular	0.00	0.00	10	-
	High (H)	Trapezoidal	10	40	65	65
COD	Low (L)	Triangular	0	0	2500	
	Intermediate (I)	Triangular	2500	6250	10000	-
	High (H)	Trapezoidal	8000	10000	12000	12000
$\%CO_2$	Low (L)	Trapezoidal	0	0	15	20
	Intermediate (I)	Triangular	15	22	30	-
	High (H)	Trapezoidal	30	35	40	40
NH_4-N	Low (L)	Trapezoidal	0	0	200	250
	High (H)	Triangular	250	1000	1000	-

Then the rule base converts fuzzy input values to fuzzy output values. It is made up of a set of fuzzy rules that describe the system's behavior and replace into mathematical modeling (C.C. Lee 1990). These rules are described as an IF–THEN statement that outlines the action to be taken in response to certain fuzzy inputs. The given rule is an instance of a built fuzzy rule base statement: IF pH is L OR $\%CH_4$ is Z OR COD is I OR $\%CO_2$ is I OR NH_4-N is L THEN Phase Index is Acid Formation, where L, Z, I Stands for low , zero and intermediate respectively. The MAX-MIN fuzzy inference approach was used to calculate a numerical value representing the cumulative effect of all of that was generated by an input value.

Defuzzification happens as the final stage of fuzzy inference. It is the process of converting a fuzzy member into a crisp member or transforming a fuzzy set into a crisp set (Abdallah et al., 2009). It often requires weighing and combining a number of fuzzy sets into a computation that yields a single crisp value as the output. Centroid defuzzification method is used here. The defuzzified value, m, could be computed using this approach as follows:

$$m=\sum_{i=1}^{n} mi.ci \,/ \sum_{i=1}^{n} mi$$

Where, n denotes the quantity of rules in total, mi is the degree of the output fuzzy set's (i) membership , is the value linked with the maximum value of output fuzzy set i. The output is a function of all the input factors, and surface plots were constructed to assist visualize the non-linear properties of the Phase Index by altering two variables while the other variables stayed unchanged. This could produce an endless number of response surfaces. However, if the response surfaces are grouped for each couple of inputs, the amount of possible groups of response surfaces equals the combination, C (n, 2) = n! / 2! (n - 2)! where n is the quantity of input variables. One of the key benefits of the fuzzy logic system is the non-linear change in response strength for varied input variable values (Lee 1990).

2.3 Establishment of Model

The FIS was constructed using the MATLAB™ R2017a software with the Fuzzy Logic Toolbox.

3. RESULT AND DISCUSSION

3.1 Verification of the model

The model was built and verified using the data from a constructed sanitary landfill lysimeter at KUET campus. Based on many input data, the Phase Calculator was able to analyse the phase state and find transition zones between phases. When pH is 7.23, %CH4 is 52.4, COD is 6000, NH4-N is 861 then the phase index becomes 1.36 which indicates that the phase is transforming from transition phase to acid formation phase in this study, which is illustrated in Figure-7.

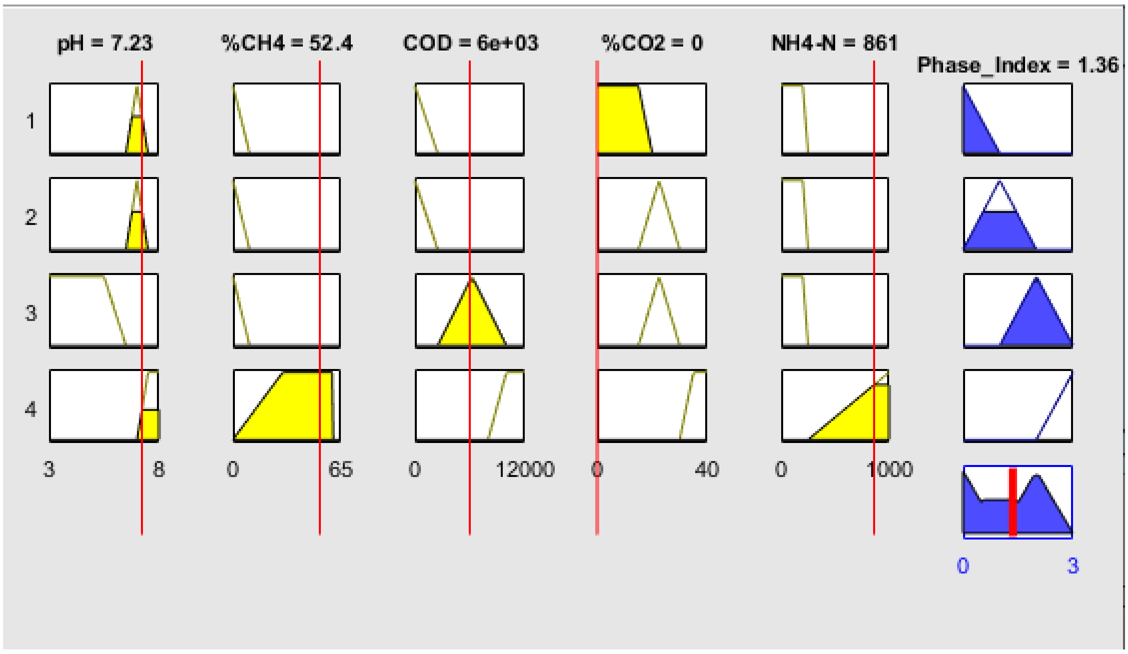

Figure-7: Phase index for different input in rule viewer

3.2 Response Surface of Parameters

As the value is closer to transition phase that defines the phase is just hast started to transform into acid formation phase. The output Phase Index is an actual value that represents the landfill's precise transitional phase. This feature is extremely useful since it allows the in-situ growth needs of the bacterial population inside the landfill to be determined using interpolation techniques. As a consequence, a safe and smooth transition from one operating phase to the next is possible. Response surface is the view of predictor factors in order to shift the response in the desired direction (Tanikic` et al., 2016). Response surface for pH and %CO_2 with phase index is shown in Figure 8.

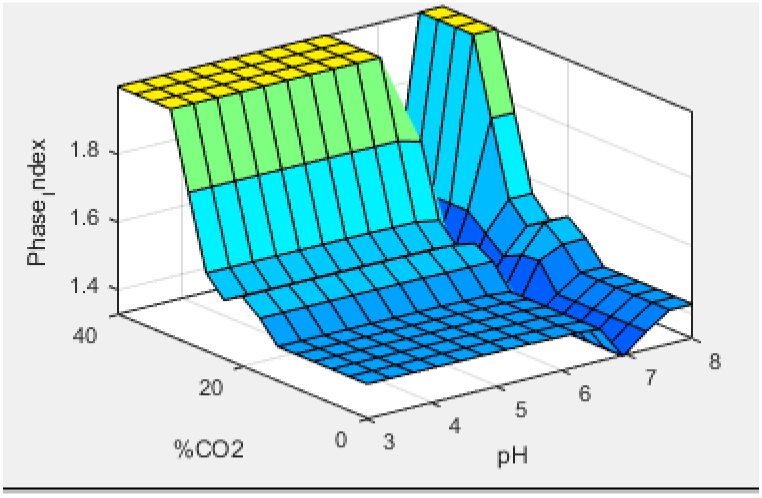

Figure-8: Response surface for pairs of input variables: CO_2 and pH

Response surface used to show the result of output with respect to two different variables. Here response variable is Phase index and independant variables are %CO_2 and pH. Figure-8 shows how operational phase changes with different value of %CO_2 and pH. Response surface for CO_2 and CH_4 with phase index is shown in Figure-9 which also shows

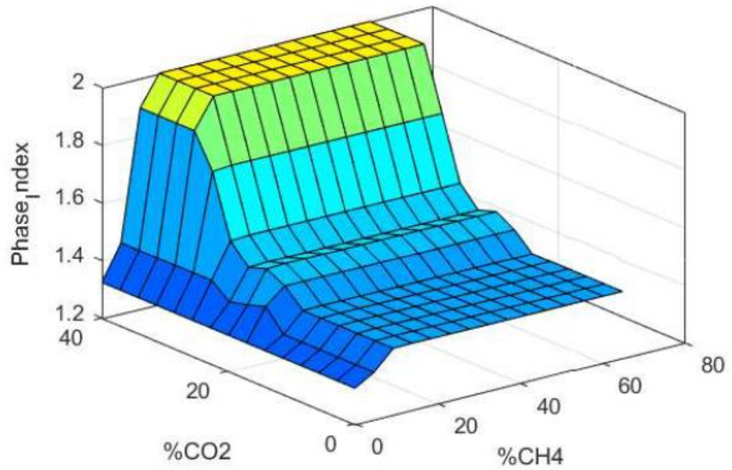

Figure-9: Response surface for pairs of input variables: %CO_2 and %CH_4

The 2-dimensional plane where all points that have the equal respone. The figure clearly demonestrates how the operational phase changes with the value of %CO_2 and %CH_4. Response surface for CO_2 and COD is with phase index is shown in Figure-10 also shows

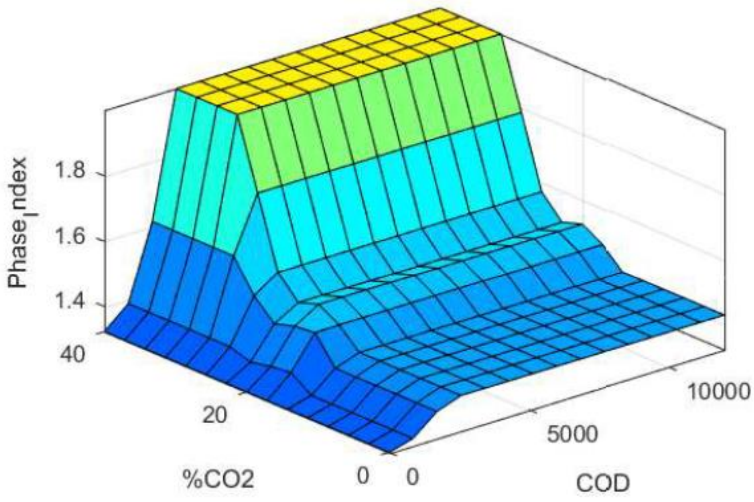

Figure-10: Response surface for pairs of input variables: $\%CO_2$ and COD

How the phase changes with different values of $\%CO_2$ and COD. And likely the previous response surfaces explained , for all the defined ranges of pH(3-8) and NH_4-N(0-1000) changes of operational phase is shown in the Figure-11.

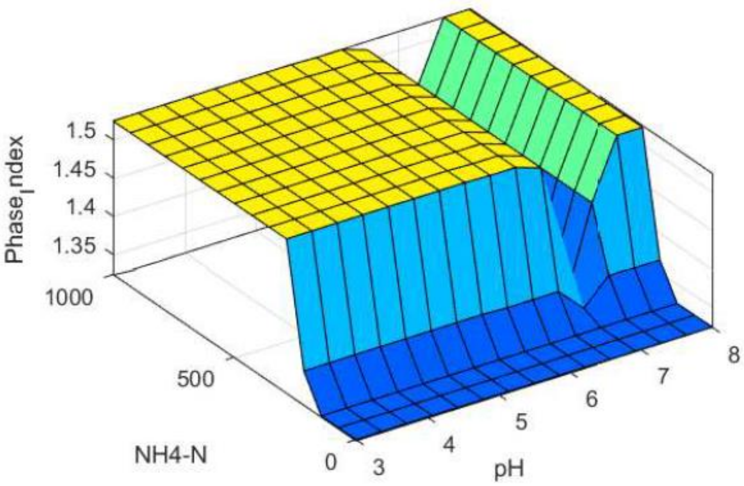

Figure-11: Response surface for pairs of input variables: $\%CO_2$ and COD

4. CONCLUSIONS

A fuzzy logic controller was designed to evaluate its instantaneous operational phase of a landfill at a particular moment using several parameters. The output phase index is a quantitative value of real number which is ranged from 1 to 3 that represents the specific transitioning phase of the landfill. This model helps to predict any transitioning phase with its degree of transition. If the output value comes between 0 to 1 that means the phase is shifting from aerobic phase to transition phase. Output value between 1 to 2 means the phase is shifting from transitional to acid formation. The closer value to 2 indicates the pahse is closer to acid formation and the closer value to 1 indicates the phase is just started shifting towards acid formation. Similarly for the value of output 2 to 3 indicates the shifting phase of methane formation from acid generation.

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