Optimization of Different Parameters Affecting Biogas Production from Rice Straw: An Analytical Approach

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Abstract **- The experimental and analytical study is to obtain the optimal conditions for biogas generation from anaerobic digestion of rice straw using Response Surface Methodology (RSM). This experiment is carried out using 1m3 floating drum anaerobic digester. The parameters temperature, pH, and substrate concentration and agitation time on biogas production from rice straw were investigated. The experimental results showed that the linear model terms of temperature, substrate concentration and the pH , agitation time had significant of interactive effects (P<0.05) were studied on biogas. The highest level of biogas 0.72m3 is produced at optimum temperature 50°c, pH 7.5, substrate concentration 110.70 kg, and agitation time of 5sec respectively.**

Keywords - Response Surface Methodology (RSM), rice straw, substrate concentration, optimum temperature, anaerobic digester.

I. INTRODUCTION

The anaerobic digestion (AD) is a biological process and group of microorganism presents in the organic matter. In this wastes are converting into simple and stable end products in absence of oxygen [1]. Biogas is produced by anaerobic manner of organic wastes, agricultural wastes and energy crops. The biogas is a type of biofuel [2]. Anaerobic digestion technique is mainly used for the treatment of any organic waste produced on large scale with an annual growth rate of 30% during recent ten years [3]. The methanogenesis and microorganisms growth is mainly depend on different parameters like pH, temperature, Carbon/Nitrogen ratio, organic loading rate and digester design, inoculum, Hydro Retention Time [4]. AD process can be summarized in following four stages hydrolysis, acetogenesis, acidogenesis, and methanogenesis [5]. The biogas anaerobic digestion of rice straw converted into life fuel and also transformed to organic fertilizer with high quality [6]. Biogas production using rice straw in high concentration having more advantage compare to low concentration using rice straw can prevent crusting and produce higher volume of biogas [7]. The C/N ratio of rice straw in biogas production found the best ratio of 20:1 to 30:1[8]. Generally methanogenesis stage the methanogenic bacteria production are carried out in optimal pH conditions are 6.5-7.5 range for various substrate with anaerobic digestion process[9]. Response surface methodology (RSM) is considered a useful mathematical and statistical technique for analyzing several independent parameters, experimental design, and evaluation of factors, optimization of different conditions [10].The optimization of different process parameters affecting biogas production. It is one of complex process with more number of interactive effects for controlling process parameters. The optimization is producing accurate results about interactive process parameters and which improves the production of biogas significantly [11]. The traditional "one or more variable at a time approach" for medium optimization disregards the complex between various components of the RSM. It is one of the analytically based experimental designs such as placket-burman design and response surface methodology (RSM). Mainly used to study the effect of factors and estimating optimum levels of the experiments [12]. In the last seven years RSM has been used in so many, industries to optimizing and estimating the interactive effects of independent variables in chemical and biochemical process involved in anaerobic digestion [13].

$$C_aH_bO_CN_d + [(4a\text{-}b\text{-}2c+3d)/4]\ H2O \rightarrow [(4a+b\text{-}2c\text{-}3d)/8]\ CH4 + [(4a\text{-}b+2c+3d/8)]\ CO2 + dNH_3 \quad (1)$$

Above (1), general biochemical reaction mechanism is mainly for production of biogas from floating drum anaerobic digester. [14]. The main aim of this study was to investigate the effects of temperature, pH, substrate concentration, and agitation time as well as their

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interactive effects on biogas production in rice straw using RSM.

II. EXPERIMENT AND METHODS

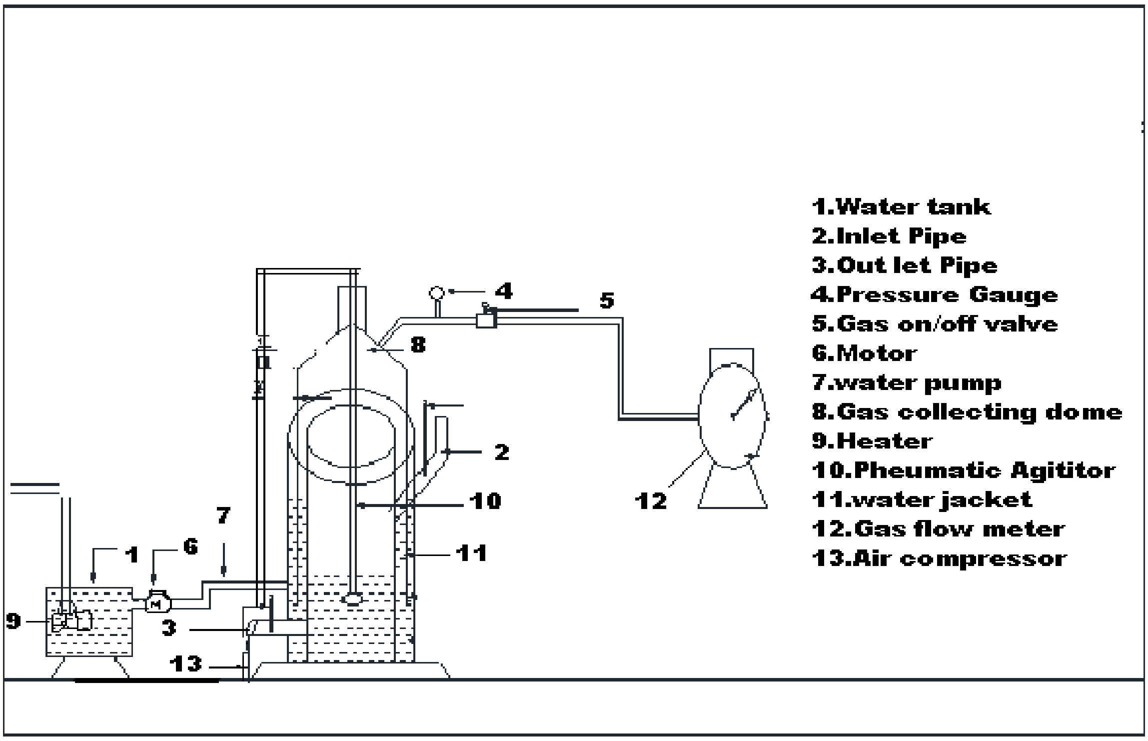

Fig.1 schematic view of the Experimental Setup

Rice straw (RS) was obtained from a local villager near Chidambaram. Firstly, rice straw was cut to normally 5-10cm length then washed thoroughly with tap water and then air-dried. It was grinded to 2-3mm size using hammer mill and further treatment. Thirty experiments were conducted using $1m^3$ floating drum anaerobic digester. The fresh cow dung and water used inoculum of this experiment. Rice straw used as a substrate 90-130kg and also added same quantity of water. The digester operating temperature at 40 to 60°c in thermophilic range were electric heater is used as a heating element. Biogas production measured using gas flow meter. Pneumatic stirrer was used to agitate the digester slurry with electric timer. A digital PH meter was used to calculate pH of the digester slurry.

III. DESIGN OF EXPERIMENTS (DOE)

The experimental design was carried out based on central composite design (CCD) with response surface methodology (RSM). It applied for four independent variables each at two levels to fit second order polynomial model. The software design expert version 9.0state-Ease.inc was used. The independent variables of temperature, pH, substrate concentration, agitation time were analyzed using optimization techniques. The full experimental plan with respect to their actual and coded forms is listed below table I.

TABLE I. EXPERIMENTAL PLAN WITH RESPECT TO ACTUAL AND CODED VALUES

Factor	Variable	Coded levels of variables				
		-2	-1	0	1	2
A	Temp°C	40	45	50	55	60
B	pH	6.8	7.0	7.2	7.4	7.6
C	Substrate Concentration (kg)	90	100	110	120	130
D	Agitation time (S)	2	4	6	8	10

IV. STATISTICAL ANALYSIS

Analysis of variance (ANOVA) was used for analysis of regression co-efficient, prediction equation, and case statistics. The experimental results of RSM were fitted using the following second order polynomial regression equation:

$$Y = \beta_0 + \text{€}\beta_i X_I + \text{€}\beta_{ii}\ X\ _{i2} + \text{€}\beta_{ij}\ X_i\ X_j \quad (2)$$

Where Y is the measured response, β_0 is the intercept term, β_{ii} are quadratic coefficient, β_{ij} are interaction coefficient, and Xi and X_j are coded independent variables. The following equation was used for coding the actual experiment values of the factors in the range of (-1 to +1):

$$X_i = \frac{x_i - x_j}{\Delta Ki} \quad (3)$$

$$\Delta x_i,\ i = 1, 2, 3, k$$

Where x_i is the dimensionless value of an independent variable, X_i is the real value of an independent variable, X_0 is the value of X_i at the corner point and Δx_i is the step change. Statistical analysis of the data was performed by design package design expert 9.0 to evaluate the analysis of variance to determine the significance of each term in the equations fitted and estimate the goodness of fit in all case. The polynomial equation was represented in three dimensional response surface plots to indicate the interactive effects of variables. The optimal concentration of critical variables was obtained by analyzing 3D Plots.

V. RESULTS AND DISCUSSION

TABLE II. CCD MATRIX FOR FOUR VARIABLES WITH ACTUAL BIOGAS PRODUCTION

Run Order	A	B	C	D	ACTUAL BIOGAS m^3	PREDICTED BIOGAS m^3
1	0	0	0	0	0.72	0.722857
2	-1	-1	1	-1	0.39	0.3975
3	-1	1	1	-1	0.41	0.420417
4	-1	1	1	1	0.39	0.3925
5	1	-1	-1	-1	0.31	0.315833
6	-1	-1	1	1	0.42	0.412083
7	0	0	0	-2	0.41	0.387083
8	-1	-1	-1	1	0.4	0.390833
9	1	1	1	1	0.43	0.417083
10	0	-2	0	0	0.38	0.38875
11	1	1	-1	1	0.37	0.370833
12	0	0	2	0	0.36	0.355417
13	0	0	0	0	0.73	0.722857
14	-1	1	-1	-1	0.33	0.334167
15	1	-1	1	-1	0.44	0.432083
16	1	1	-1	-1	0.36	0.36375
17	1	-1	-1	1	0.38	0.365417
18	0	0	0	0	0.74	0.722857
19	0	0	0	2	0.39	0.40875
20	0	0	0	0	0.71	0.722857
21	-2	0	0	0	0.45	0.442083
22	1	1	1	-1	0.46	0.4775
23	0	0	0	0	0.73	0.722857
24	-1	1	-1	1	0.37	0.37375
25	0	0	0	0	0.72	0.722857
26	1	1	1	1	0.41	0.414167
27	0	0	-2	0	0.22	0.220417
28	-1	1	-1	-1	0.3	0.30875
29	2	0	0	0	0.47	0.47375
30	0	2	0	0	0.43	0.417083

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TABLE III. REGRESSION ANALYSIS FOR THE PRODUCTION OF BIOGAS FOR QUADRATIC RESPONSE SURFACE MODEL FITTING (ANOVA)

Source	**Sum of Squares**	**Degree of Freedom**	**Mean Square**	**F Value**	**p-value Prob > F**
Model	0.619328	14	0.044238	220.576	0.00127 <significant
A-Temperature	0.001504	1	0.001504	7.5	0.015231
B-pH	0.001204	1	0.001204	6.004155	0.027023
C-Substrate concentration	0.027338	1	0.027338	136.3089	6.28E-09
D-Agitation time	0.000704	1	0.000704	3.51108	0.080575
AB	0.000506	1	0.000506	2.524238	0.13296
AC	0.000756	1	0.000756	3.770776	0.071177
AD	0.001056	1	0.001056	5.26662	0.036582
BC	6.25E-06	1	6.25E-06	0.031163	0.862238
BD	0.001806	1	0.001806	9.006233	0.008954
CD	0.004556	1	0.004556	22.71814	0.00025
A^2	0.122286	1	0.122286	609.7363	1.46E-13
B^2	0.177836	1	0.177836	886.717	9.28E-15
C^2	0.3275	1	0.3275	1632.965	1E-16
D^2	0.1834	1	0.1834	914.4613	7.39E-15
Residual	0.003008	15	0.000201		
Lack of Fit	0.002458	10	0.000246	2.234848	0.193932
Pure Error	0.00055	5	0.00011		
Cor Total	0.622337	29			

SD= 0.014162; Mean= 0.454333; R-Square= 0.995166; Adj R-Squard= 0.990654; C.V. %= 3.117043; Pred R-Square= 0.975974; PRESS= 0.014952; Adeq Precision= 50.3884

The optimal levels for the independent variables and the effect of their interaction on biogas production were conducted in 30experiments further explored using the central composite design of RSM. By applying multiple regression analysis on the experimental data, the second-order polynomial equation (5) was derived to explain the biogas production.

$$Biogas = 0.725 + 0.007917A + 0.007083B + 0.03375C + 0.005417D + 0.005625AB + 0.006875AC - 0.00813AD - 0.00063BC - 0.01063BD - 0.01688CD - 0.06677A^2 - 0.10927C^2 - 0.08177D^2 \quad ...(5)$$

Where A, B, C, D are the values for Temperature, pH, and substrate concentration, agitation time respectively. Table 1 shows the actual and coded values of independent variables with experimental ranges. The full experimental plan of CCD design for studying the effects of four independent variables are listed in Table 2. The statistical significance of the second order polynomial equation was checked by an F- test (ANNOVA). All the corresponding data are shown in Table 3. The “model F-value” of 220.58 implies the model is significant. There is only 0.01% chance that an “F- value” this large could occur due to noise. The linear model terms of temperature (A), pH (B), substrate concentration(C), and agitation time (D) were significant ($P<0.05$). The quadratic model terms of pH (B^2) and substrate concentration (C^2) indicating that two variables had an individual effect on biogas yield. The interactive for all of the factors were found to be insignificant ($P>0.05$) in table III. For biogas production, the correlation co-efficient (R^2) of polynomial equation was found as 0.9951. The R^2 value indicated a measure of variability in the observed response values which could be described by independent factors. The “Adeq precision” measures the signal to noise ratio and the ratio greater than 4is desirable. The ratio found here 50.3884 which indicated an adequate signal. This model can be to navigate the design space. Here adjusted R^2 (0.9906) was also very high, which indicate the higher significance of the model. The “Pred R-Squared” value of 0.9906 in this value indicates the good agreement between the observed and predicted values. The higher of CV, which gives the lower reliability of the experiment but here a lower value of (3.11%), indicated a greater reliability of the experiment. This model showed standard deviation and mean values of 0.141 and 0.4543 respectively.

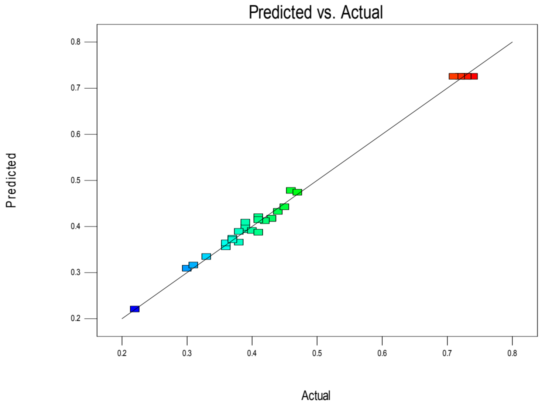

Fig.2 Predicted vs Experimental biogas values

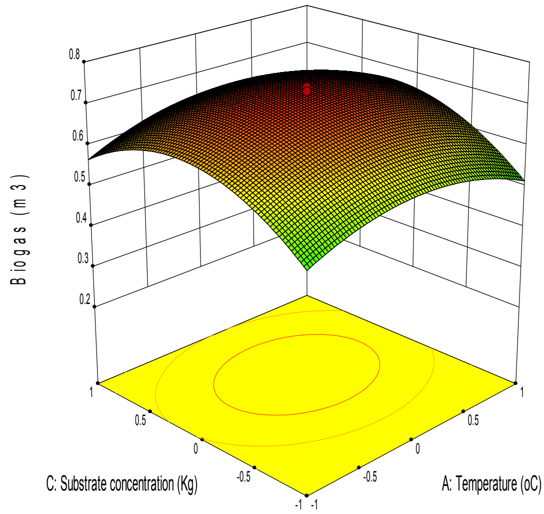

Fig.3 (b): Three-dimensional response surface plot for biogas production showing the interactive Effects of Substrate concentration and temperature.

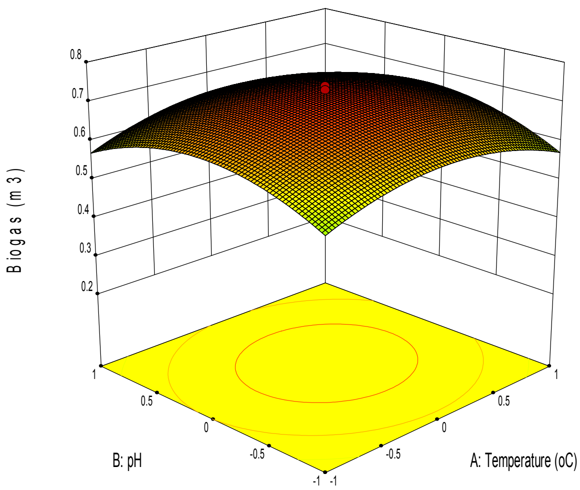

Fig.3 (a): Three-dimensional response surface Plot for biogas production showing the interactive Effects of Temperature and pH.

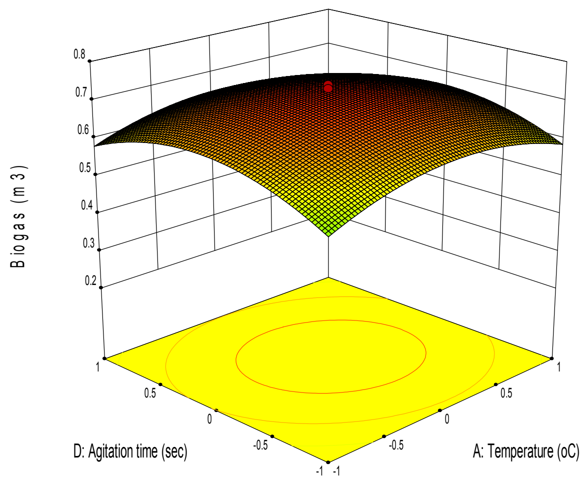

Fig.3 (c): Three-dimensional response surface Plot for biogas production showing the interactive Effects of Agitation time and temperature.

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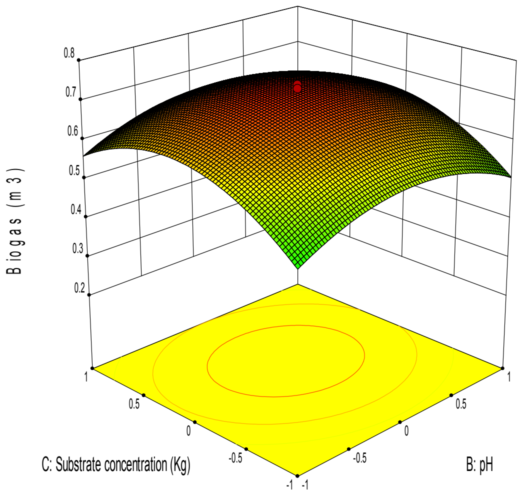

Fig.3 (d): Three-dimensional response surface Plot for biogas production showing the interactive Effects of Substrate concentration and pH.

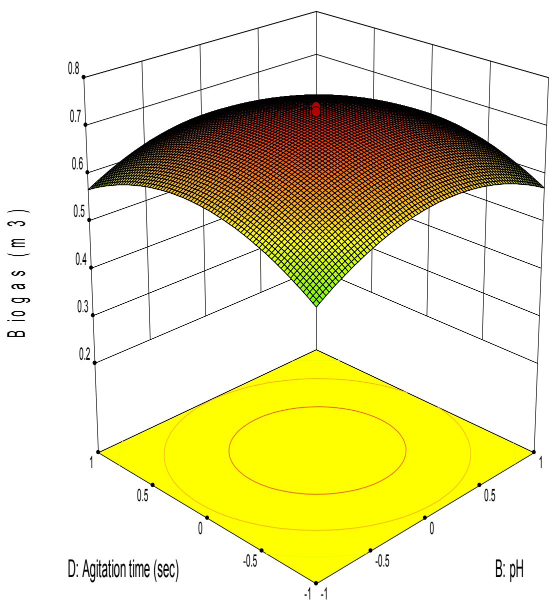

Fig.3 (e): Three-dimensional response surface Plot for biogas production showing the interactive Effects of Agitation time and pH

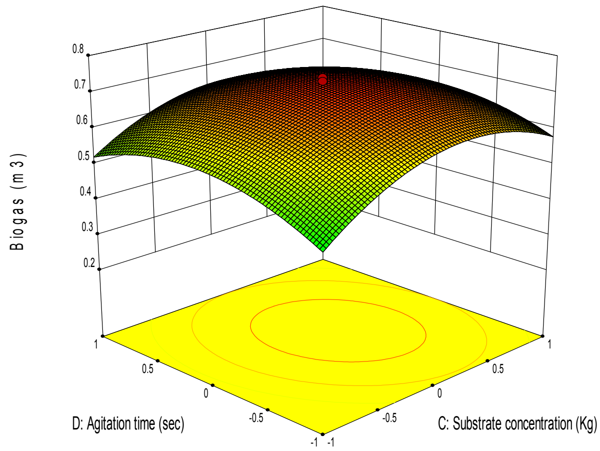

Fig.3 (f): Three-dimensional response surface Plot for biogas production showing the interactive Effects of Substrate concentration and Agitation time.

The experimental biogas production was close to the predicted value shown in Fig.1. The interaction effects of biogas production were studied by plotting 3D surface curves. The plotting 3D surface curves of the calculated response (biogas production) from the interaction between the variables are shown in Fig. 3(a),3(b),3(c),3(d),3(e) and 3(f). The Fig. 3(a),3(b),3(c) shows the dependency of biogas production increases with increase in temperature 50°c and thereafter biogas production decrease with further increase in temperature of the digester. The same trend was observed in Fig. 3(a), 3(d), 3(e) which shows the dependency of biogas production on acid production (pH). The biogas production increases with increase in pH 7.5 and thereafter biogas production decreases with further increase in pH. Fig. 3(b), 3(d), 3(f) shows the dependency of biogas production on substrate concentration. The biogas production increases with increase in substrate concentration 110.70kg and thereafter biogas production decreases with further increase in substrate concentration. The dependency of biogas production in agitation time from the Fig. 3(C),3(e),3(f) here biogas production was increase with increase in agitation time 5sec and thereafter biogas production decrease with further increase in agitation time . The optimum conditions for maximum production of biogas were determined by response surface analysis and also estimated by optimal tool using "Design Expert 9.0" the experiment optimal conditions are Temperature

(50°c), acid production pH (7.5), substrate concentration (110kg), and agitation time (5sec). The predicted results are shown in Table II.

VI. VALIDATION OF THE EXPERIMENTAL

Validation of the experimental model was tested by carrying out the continuous process under optimal operation conditions. Three repeated experiments were performed and the results are compared. The biogas obtained from experiments was very close to the actual and predicted by the regression model, which proved the validity of the model. At these optimized conditions, the maximum biogas production was found to be $0.72m^3$.

VII. CONCLUSION

In this work biogas production from anaerobic digestion of rice straw were optimized by RSM. Using placket-Burman design temperature, pH, and substrate concentration and agitation time was found to be the most significant variables, which significantly enhanced biogas production. The optimal levels of parameters were obtained as temperature (50°c), pH (7.5), substrate concentration (110.75kg), and agitation time (5sec). This study showed that the rice straw constitutes a good C/N ratio for the production of biogas. Using the optimized conditions, the produced biogas reaches $0.72m^3$. The results show a close agreement between the expected and obtained production level.

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