Optimization of Generated Waste Plastic Fuel through Mathematical Approach

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ABSTRACT
An estimated 19–23 million tonnes of plastic garbage are dumped annually into lakes, rivers, and oceans, where it contaminates aquatic ecosystems. This pollution disrupts habitats and fundamental ecological processes, diminishing ecosystems' resilience to climate change and negatively impacting the livelihoods, food security, and the general health of millions of people globally. We suggest a fuzzy approach to the Taguchi method in this work. The control parameters are converted into triangular intuitionistic fuzzy numbers to manage imprecise data, and a ranking technique is applied to organize it effectively. Next, we apply the Taguchi approach to examine the factors affecting the production of plastic waste fuel. The orthogonal array L9 is constructed in order to determine the optimal conditions for the parameters. The ANOVA table, which reveals the key factors impacting production, is then constructed by evaluating the S/N ratio.

Keywords: Plastic wastes, pyrolysis, Taguchi design, Triangular Intuitionistic fuzzy Number,ANOVA, S/N Ratio.

1. INTRODUCTION

L. A. Zadeh [2] invented the fuzzy set in 1965. As an expansion of Lotfi Zadeh's fuzzy set concept, Atanassov [3] introduced intuitionistic fuzzy sets in 1983. Intuitionistic fuzzy sets are made up of elements that fluctuate in their degrees of membership and non-membership. (IFS). Zadeh created fuzzy numbers as a useful solution for handling uncertain numerical quantities. Among the extensions of Intuitionistic Fuzzy Numbers are trapezoidal IFN (TrIFN), interval-valued trapezoidal IFN (IVTrIFN), Pythagorean IFN (PIFN), and triangular IFN (TIFN). (IFN). Nevertheless, using the triangle intuitionistic fuzzy ranking technique for imprecise data ranking, this study will only consider triangular intuitionistic fuzzy numbers (TIFNs). Konishi Mikihiko and others. [5] proposed using the fuzzy sets idea to provide an ANOVA method for the fuzzy interval data. The Taguchi method, is a statistical approach used to optimize manufacturing processes and enhance product quality. Its core objective is to ensure the creation of robust and dependable products or processes by systematically identifying and minimizing variability and sensitivity to external factors, often referred to as noise factors. This study used Taguchi methods in conjunction with triangular intuitionistic fuzzy numbers (TIFNs) and their ranking mechanism., can optimize manufacturing processes more effectively, even when dealing with uncertainty. The rapid increase in plastic production and use, driven by urbanization, industrial growth, and the availability of cheap plastic resources, has created a critical situation. Thrown-away plastic debris has grown to be a serious problem, endangering aquatic biodiversity and human health as well as harming terrestrial and marine ecosystems [4]. The thermoplastic polymers HDPE and LDPE are derived from ethylene monomer. LDPE is characterized by its relatively low density, flexibility, and transparency, while HDPE is comparatively rigid, impact-resistant, and temperature-tolerant, reaching up to 120 °C without experiencing any adverse effects. Pyrolysis is the process of heating up materials to high temperatures without air, causing them to break down and change their chemical composition. This process involves breaking larger molecules into smaller ones through a chemical reaction triggered by heat. It's also known as thermal cracking, thermolysis, or depolymerization [4]. Pyrolysis is a viable method that can be used to transform plastic waste into fuel for diesel engines, helping to alleviate the fuel problem.

2. Preliminaries

Definition 2.1 [1]

An IFS Á in X is an object having the form $Á = \{\langle x, \mu_{Á}(x), \nu_{Á}(x) : x \in X\rangle\}$, where the$\mu_{Á}(x)$: X → [0, 1] and$\nu_{Á}(x)$: X → [0, 1] defines the degree of membership and degree of non-membership, respectively, of the element $x \in X$to the set Á, which is a subset of X, for every element of $x \in X$,$0 \le \mu_{Á}(x) + \nu_{Á}(x) \le 1$.

Definition 2.2[1]

Á is called A triangular intuitionistic fuzzy number

Á = $(x_1, x_2, x_3)(x_1', x_2, x_3')$ where $x_1' \le x_1 \le x_2 \le x_3 \le x_3'$with the following membership function$\mu_{Á}(x)$and non-membership function$\nu_{Á}(x)$is given below,

$$\mu_{Á}(x) = \begin{cases} \dfrac{x - x_1}{x_2 - x_1} & if \quad x_1 \le x \le x_2 \\ \dfrac{x_3 - x}{x_3 - x_2} & if \quad x_2 \le x \le x_3 \\ 0 & otherwise \end{cases}$$

$$\nu_{Á}(x) = \begin{cases} \dfrac{x_2 - x}{x_2 - x_1'} & if \quad x_1' \le x \le x_2 \\ \dfrac{x - x_2}{x_3' - x_2} & if \quad x_2 \le x \le x_3' \\ 1 & otherwise \end{cases}$$

Definition 2.3 [1]

definition of the triangular intuitionistic fuzzy number's ranking Á = $(x_1, x_2, x_3)(x_1', x_2, x_3')$ is defined as

$$R(Á) = \frac{1}{3}\left[\frac{(x_3' - x_1')(x_2 - 2x_3' - 2x_1') + (x_3 - x_1)(x_1 + x_2 + x_3) + 3\left(x_3'^2 - x_1'^2\right)}{(x_3' - x_1') + (x_3 - x_1)}\right]$$

Definition 2.4 [1]

Let $Á_1$and $Á_2$ be two fuzzy triangular numbers that follow intuition. The triangular intuitionistic fuzzy number set on E, The ranking of $Á_1$and $Á_2$ together with their order according to the R(.) on E, are defined as follows:

i) $R(Á_1) > R(Á_2)$ iff $Á_1 > Á_2$
ii) $R(Á_1) < R(Á_2)$ iff $Á_1 < Á_2$
iii) $R(Á_1) = R(Á_2)$ iff $Á_1 = Á_2$
iv) $R(Á_1 + Á_2) = R(Á_1) + R(Á_2)$
v) $R(Á_1 - Á_2) = R(Á_1) - R(Á_2)$

3.Taguchi Method

The Taguchi Method is a statistical technique used to optimize process parameters and enhance the quality of manufactured components. The Taguchi method consists of three main steps: design of experiments (DOE), signal-to-noise (S/N) ratio analysis, and optimization. During the DOE phase, a series of experiments is carefully designed to investigate the influence of different factors on process performance. These experiments are constructed using orthogonal arrays and this approach minimizes the number of experiments needed while ensuring comprehensive testing of all factors at varying levels, thereby enhancing efficiency and effectiveness. The following properties are essential for understanding the behavior and characteristics of HDPE oil and LDPE oil and its corresponding secondary data are given in table 1.

Table 1. Properties of HDPE oil and LDPE oil

Fuel properties	**HDPE**	**LDPE**
Density	795.45 kg/m3	530.35 kg/m3
Viscosity	0.775 poise	0.652 poise
Specific gravity	0.776	0.655
Flash point	23	24
Fire point	27	28
Cloud point	Below 2	Below 0

Pour point	-4.5 to -5	-2
Colour	Yellow, light transparent	Pale yellow

Table 2. Parameters of Control and their values

Parameters	Code	Unit	Level 1	Level 2	Level 3
Catalyst	A	gm	10	30	50
Temperature	B	°C	433.67	314.33	303.33
Time	C	min	43.67	34	26.67

Table 3. Fuzzy Number in Triangular Intuitionistic Form

	Level 1	**Level 2**	**Level 3**
A	(10, 13, 16)(4, 13, 22)	(30, 33, 36)(24, 33, 42)	(50, 53, 56)(44, 53, 62)
B	(433.67, 436.67, 439.67) (427.67, 436.67, 445.67)	(314.33, 317.33, 320.33) (308.33, 317.33, 326.33)	(303.33, 306.33, 309.33) (297.33, 306.33, 315.33)
C	(43.67, 46.67, 49.67) (37.67, 46.67, 55.67)	(34, 37, 40)(28, 37, 46)	(26.67, 29.67, 32.67) (20.67, 29.67, 38.67)

Table 4 displays the levels of the control parameters using a ranking triangle intuitionistic fuzzy number.

Table 4. Ranking Triangular intuitionistic fuzzy numberin the control parameter and their levels

	Level 1	**Level 2**	**Level 3**
A	13	33	53
B	436.67	317.33	306.33
C	46.67	37	29.67

Table 5. Design of Experimental Layout for L9 Orthogonal array of Triangular intuitionistic fuzzy number after ranking

Experiment No	Parameter Code			Response Value
	A	B	C	
1	1	1	1	105
2	1	2	2	107
3	1	3	3	108
4	2	1	2	115
5	2	2	3	118
6	2	3	1	120
7	3	1	3	123
8	3	2	1	126
9	3	3	2	130

Analysis of the signal-to-noise (S/N) ratio

During the S/N ratio analysis phase, the efficacy is measured by analyzing the balance between the signal (desired output) and the noise (undesired output). This critical study aids in identifying the ideal concentrations of components necessary to maximize the efficiency of the process or product. The S/N ratio analysis serves as the foundation for determining these optimal factor levels later on in the optimization process. The S/N ratio analysis is typically used to group performance aspects into nominal-the-best, larger-the-better, and smaller-the-better categories. The S/N ratio's "larger is better" criterion is used to optimize manufacturing.

where n is the number of values at each trial and is the value of each observed trial.

$$S/N = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_i}^2}$$

where n, is the number of values at each trial and y_i is the each observed value.

Table 6. Experimental result for Mean and S/N Ratio

Experiment No	A	B	C	Mean	S/N Ratio
1	13	436.67	46.67	105	40.4238
2	13	317.33	37	107	40.5877
3	13	306.33	29.67	108	40.6685
4	33	436.67	37	115	41.2140
5	33	317.33	29.67	118	41.4376
6	33	306.33	46.67	120	41.5836
7	53	436.67	29.67	123	41.7981
8	53	317.33	46.67	126	42.0074
9	53	306.33	37	130	42.2789

Table 7. Ideal Situations by Applying S/N Ratio

Level	A	B	C
1	40.56	41.15	41.34
2	41.41	41.34	41.36
3	42.03	41.51	41.30
Delta	1.47	0.37	0.06
Rank	1	2	3
Optimum	A3	B3	C2

This method determines optimal conditions by ranking deltas based on their impact on the process using MINITAB-17 software. Higher delta values signify greater contributions from respective parameters. The resulting optimal conditions, identified as A3, B3, and C2, are listed in Table 7. Furthermore, Figure 1 displays the highest plots for each parameter.

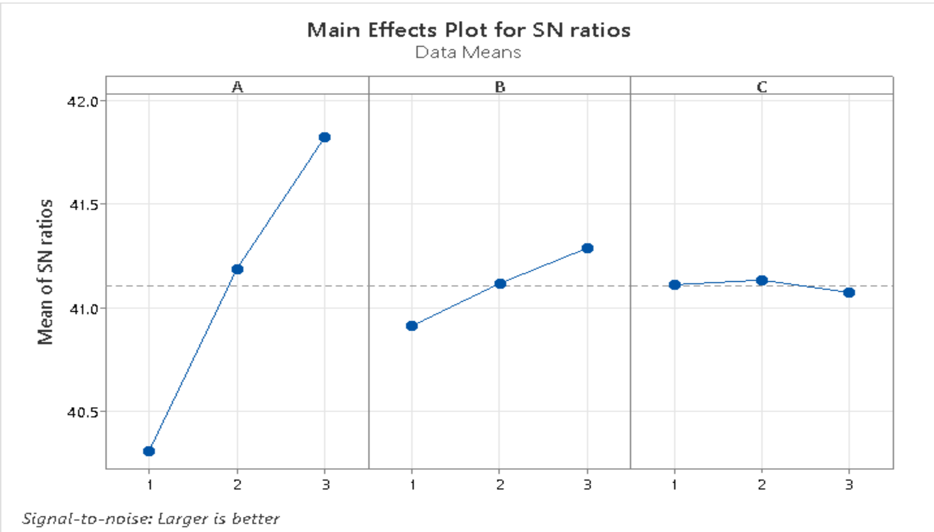

Fig 1. Plot of Main Effects S/N ratios

Table 8. Analysis of Variances (ANOVA) using S/N Ratio

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value	% Contribution
A	2	3.26089	3.26089	1.63044	298.68	0.003	93.77%
B	2	0.20042	0.20042	0.10021	18.36	0.052	5.76%
C	2	0.00529	0.00529	0.00265	0.48	0.674	0.15%
Error	2	0.01092	0.01092	0.00546			0.31%
Total	8	3.47752					100.00%

ANOVA, when combined with the Taguchi technique, helps evaluate the influence of each process parameter. This method assists in pinpointing the impact of individual parameters on plastic fuel production, enabling a more precise estimation of their percentage contribution to the process. The ANOVA F-value and percentage contribution determine the significance of each control parameter. Statistical results, obtained with a 95% confidence level, indicate that the catalyst (A), temperature (B), and time (C) affect production by 93.77%, 5.76%, and 0.15%, respectively.

CONCLUSION

In this work, triangular intuitionistic fuzzy numbers are ranked using the Taguchi method. We determined the optimal conditions by looking at the L9 Orthogonal array Experimental design. Utilizing both Anova and Signal-to-Noise (S/N) Ratio, the experimental results effectively identified the crucial elements that significantly influence the production of plastic fuel: catalyst (53), temperature (303.33), and time (34). Furthermore, the statistical analysis revealed that the catalyst had the highest percentage contribution (93.77%) to the production process, followed by temperature (5.76%) and time (0.15%).

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