Optimization compressive strength biomass pellet from compost using Taguchi method

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Abstract: Compression of pellets is important to prevent deterioration in quality for long term storage and the moisture content of pellets must be less than"20%" . In this research the quality of compost pellets was studied after drying at air temperatures of 50 ℃, 60 ℃ and 70 ℃ and air velocities of 0.5, 1, and 1.5 m/s, for the samples with particle sizes of 1.18 and 2mm (meshes of 16 and 10) and pellet diameters of 6 and 8 mm. The Taguchi quality engineering method was used to investigate the effects of the parameters on compressive strength of pellet. The orthogonal array, signal-to-noise (S/N) ratio and analysis of variance (ANOVA) were employed to analyze the effect of the parameters on compressive strength. The optimal performance for the compressive strength of pellet was obtained at first level of factor A, i.e. the particle size of 1.18 mm, air temperature of 70" ℃" and air velocity of 1 m/s.Confirmation tests verified that the Taguchi method was successful in evaluation of compressive strength of pellet.

Keywords: Compost, CS of pellet,optimization, Taguchi.

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1 Introduction

Every day a huge amount of organic wastes generate by the municipal, agricultural and agro-industrial activities and removal of the wastes causes energetic, economic and environmental problems (Castaldi and Melis, 2002). The wastes produced by food industry plants, animal manures, sewage sludge and compost can be used to replenish organic matter which is useful for soil structure and fertility improvement(Saison et al., 2006; Businelli et al., 2007). In recent years, composting has become an interesting topic of the social demand for waste treatment technology and for organic agricultural products. Composting is a relevant method for waste treatment as a high level efficient method for waste disposal which enables recycling of organic matter (Greenway and Song, 2002). Biomass materials, such as manures and farmyard compost from urban waste have high moisture content and high volume and are also non-uniform materials, which cause limitation in usage of such materials. The possible compaction of these composted solids into pellets further homogenizes and dehydrates their organic matter enhancing. Its uniformity and fertilizing properties as well as densification, such as pelleting, is a solution for these problems which increase bulk density, improve storability, reduce transportation costs and make these materials easier to handle. In such conditions, the pellets become better suited and extremely cost effective to transport over long distances. Some of other benefits of compost pellets are suitability for implanting or scattering with high precision, no dust and no pollution for environment, possibility to distribute in parallel with planting and ability of adding chemical materials for increasing the quality of pellets (Lopez-Ridaura et al., 2009; Alemi et al., 2010; Zafari and Kianmehr, 2013).

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Deterioration of pellets during storage period is important in order to keep quality of the compost. More molds generate on the surface of compost pellets than ordinary compost with the same moisture content. It is advised to reduce the moisture content of the pellets to 15% or less, because deterioration by condensation is caused even at 20% moisture content (Hara, 2001).For success of the drying process, the quality of the densified products must meet the consumer requirements and market standards. The effectiveness of the inter-particle bonds, created during the densification process, has been measured in terms of strength. Recently, several studies have been undertaken onprocess parameters and biomass properties on the mechanical quality of pellets produced with biomass material (Tabil and Sokhansanj, 1966; Mani et al., 2003; Tumuluru, 2014; Zafari and Kianmehr, 2014; Elio Romano et al., 2014). There is no report in the literature on the influence of drying parameters on compression strength of pellets from composted.The objective of this study was to investigate the effects of particle size, diameter of pellet, drying air temperature and drying air velocity on compression strength of compost pellets, using Taguchi method.

2 Materials and methods

2.1 Materials

Compost was obtained from composting laboratory in College of Abouraihan, University of Tehran and prepared for experiments. The compost was produced by turned windrow composting method using organic matters or biodegradable wastes, such as urban waste, animal manure and crop residues. Turned windrow composting is a method for production of compost in windrows using mechanical aeration that represents a low technology and medium labour approach and produces uniform compost.Physical and chemical properties of compost, used in the experiment, are shown in Table 1. The samples were screened through two sieves with sizes of 2 and 1.18 mm(meshes of 10 and 16, the American standard).

Table 1Physical and chemical properties of compost

Apparent Bulk Density, g/cm^3	Actual Bulk Density, g/cm^3	Repose Angle, degree	Porosity , %	Ratio Hasner	N, %	P, %	K, %	pH	CEC	EC
0.7	1.55	71	58	2	2.3	0.54	1.6	7.4	125	1.57

A laboratory scale pellet extruder was used to manufacture the pellets in this study. Single screw extruder is a pelleting machine that has a barrel into which the raw material is forced by a screw (Figure 1).

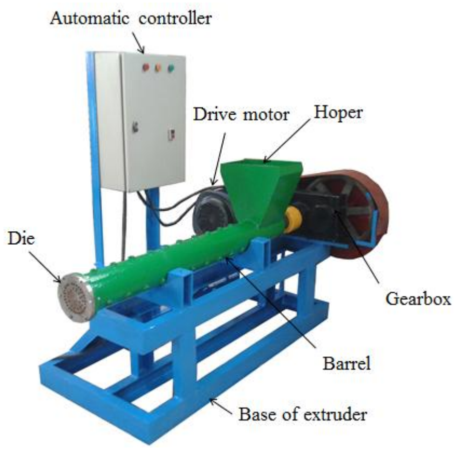

Figure 1single screw extruder used for producing pellets

Pellets were dried under controlled conditions in laboratory scale in order to focus on the pelleting process (production and drying). Moistened pellets were placed in sealed plastic bagsand kept in a cold store at 4 ℃ for at least 48 h to distribute the moisture evenly through the samples. About 30g of sample was dried at 104 ℃ ±1 ℃and the samples were weighed every 48 h. The samples were dried until the mass change was less than 0.01 g between the two weighing intervals (Doymaz, 2005). Initial moisture content of compost pellet was 54.18%. The drying experiments were performed at air temperatures of 50 ℃, 60 ℃ and 70 ℃ and air velocities of 0.5, 1 and 1.5 m/s. The drying experiments were performed by using a laboratory scale batch dryer, developed at the Department of Agrotechnology, College of Abouraihan, University of Tehran.

2.2 Methods

Compression Strength(CS) (crushing resistance or hardness) is the maximum crushing load that a pellet can withstand before cracking or breaking. The tensile strength of the densified products may be determined using the diametrical compression test. The tensile strength is related to the adhesion forces between particles at all contact points in the agglomerate (Pietsch, 2002; Tabil, 1966). Diametrical compression test is pre-dominantly used for testing tablets in the pharmaceutical industry (Tabil, 1966). Compression strength test simulates the compressive stress due to weight of the upper pellets on the lower pellets during storage in bins or silos as well as crushing of pellets in a screw conveyor. Compressive strength is an important factor in storage and transportation. The CS of pellets was determined by biological material devise test (BMT) (Figure 2). A pellet was placed between two horizontal plates and was compressed radically (Rhén et al., 2005; Zafari and Kianmehr, 2014). A data logger was used for registering of force (F). An increasing load with a constant rate was applied until the test specimen failed by braking. Pellets with equal length (20±1 mm) were used to reduce the effect of length (L) variation on CS.

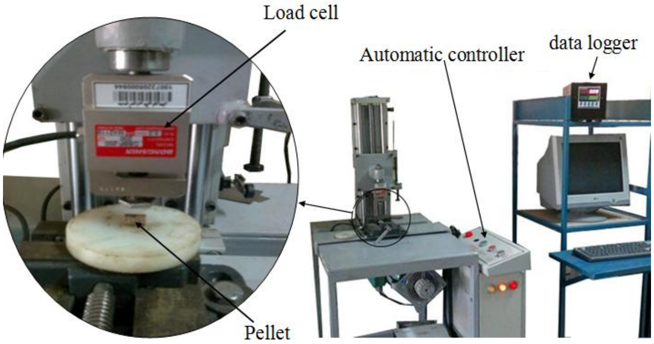

Figure 2The laboratory equipment and operating principle of pellets strength test

In this study, the Taguchi quality engineering method was used to optimize the parameter combination and obtain the maximum CS of pellet. The goal of the Taguchi method is increasing the number of levels and decreasing the cost and time or number of experiments. Therefore, experiments were designed through the use of this method (Zhang et al., 2006).

Some controllable factors that can affect CS of pellet are diameter of pellet, particle size, air temperature and air velocity.These factors were selectedand used as control factors at two or three levels for experiments(Table2).

Table 2Input factors and their levels used in the experiments

Parameter	Symbol	Level1	Level2	Level3
Diameter of pellet	A	6(mm)[a]	8(mm)	-
Particle size (mesh)	B	16 (1.18 mm)	10(2mm)[a]	-
Air temperature	C	50 ℃[a]	60 ℃	70 ℃
Air velocity	D	0.5 (m/s)[a]	1 (m/s)	1.5 (m/s)

Note: a Initial parameter

Based on the Taguchi method, a$L_{36}(2^2 \times 3^2)$ orthogonal array table with 36 rows was prepared for the control factors (Table 3). The rowscorrespond to the number of experiments that need to be performed.

Table 3 Design matrix and the results for CS of Pellet

Ex.	Level of Factors				CS of pellet	Ex.	Level of Factors				CS of pellet
	A	B	C	D			A	B	C	D	
1	1	1	1	1	110.25	19	2	1	1	2	114.25
2	1	1	2	2	111.10	20	2	1	2	3	116.10
3	1	1	3	3	116.35	21	2	1	3	1	118.35
4	1	1	1	1	119.62	22	2	1	1	2	121.62
5	1	1	2	2	112.55	23	2	1	2	3	114.55
6	1	1	3	3	118.25	24	2	1	3	1	122.25
7	1	1	1	1	123.74	25	2	1	1	3	125.74
8	1	1	2	2	129.54	26	2	1	2	1	127.54
9	1	1	3	3	129.45	27	2	1	3	2	130.45
10	1	2	1	1	100.15	28	2	2	1	3	103.15
11	1	2	2	2	99.480	29	2	2	2	1	106.48
12	1	2	3	3	107.45	30	2	2	3	2	117.45
13	1	2	1	2	102.78	31	2	2	1	3	104.78
14	1	2	2	3	105.48	32	2	2	2	1	110.48
15	1	2	3	1	109.74	33	2	2	3	2	119.74
16	1	2	1	2	106.68	34	2	2	1	3	113.68
17	1	2	2	3	105.78	35	2	2	2	1	117.78
18	1	2	3	1	111.54	36	2	2	3	2	124.54

In Taguchi method, a loss function is used to put the cost of deviation from the target into the perspective. There are three categories of loss function based on the quality characteristics of the response; lower the better (LB), nominal the best (NB) and higher the better (HB). In this paper, the higher CS of pellet is the indication of better performance. Hence, the definition of the loss function for N repeated experiments is Equation 1:

$$L_{HB}=\frac{1}{N}\sum_{m=1}^{N}\frac{1}{{y_m}^2} \qquad (1)$$

The loss function is further transformed into a signal-to-noise (S/N) ratio which provides a measure of the impact ofnoise factors on performance.TheS/N ratio of N repeated experiments, for CS of pellet output, can be expressed as Equation 2:

$$\eta=-10\log(L_{HB}) \qquad (2)$$

3 Resultsand discussion

A response table was generated to show the signal to noise (S/N) ratio for CS of pellets (Table 4). The response table shows the average S/N ratio for each factor level. For instance, the average S/N for A1 is calculated by averaging S/N ratio for the experiments No. 1 through No. 36, where the level of factor A is at level 1 (Taguchi, 2004).

Table 4Signal to Noise Values for CS of Pellets

Parameters	S/N by factor level		
	Level 1	Level 2	Level 3
A	40.75	41.53	-
B	41.68	40.61	-
C	40.97	41.01	41.45
D	41.16	41.18	41.09

The optimal level of the parameters and the better performance were indicated by greater values of S/Nratio. As can be seen from Table 4, the optimal parametersto achieve the maximum CS of pellet was obtained at second level of factor A(8mm),first level of factor B (1.18 mm),third level of air temperature (70 ℃)and second level of air velocity (1 m/s).Verification experiment was done for the same optimum conditions and maximum CS of pellet was obtained as 130.45 N. Figure 3 shows the effect of parameters on the CS of pellet.

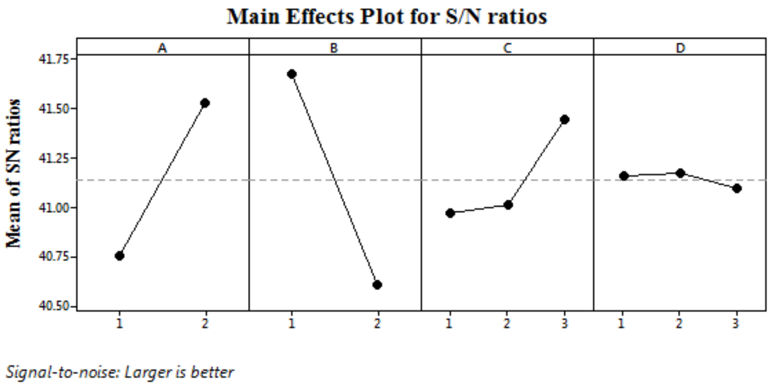

Figure 3The effect of parameters on CS of pellet

3.1Analysis of variance

Analysis of variance (ANOVA) was used to study the relative importance of the input parameters and determination of the optimal combinations of input parameters. The results of ANOVA for the CS of pellet at 90% confidence level (risk α=0.1) are presented in Table 5.In ANOVA table, F_{value} for factor *i*is defined as Equation 3:

$$F_{value}=\frac{Adj\ MS_i}{AdjMS_E} \qquad (3)$$

Table 5ANOVA test results for CS of Pellet

Parameters	DF_i	Seq SS_i	$AdjMS_i$	F-value	P-value	Contribution, ρ%
A	1	220.03	220.03	6.41[a]	0.017	7.11
B	1	1051.27	1051.27	30.64[a]	0.000	38.95
C	2	308.01	154.00	4.49[a]	0.020	9.17
D	2	36.40	18.20	0.53	0.594	0.00
Error	29	994.91	34.31			44.46
Total	35	2610.61				100

Note: aAt least 90% confidence,Seq SS_i- Sequential sums of squares, P-probability that exceeds the confidence.

Where$AdjMS_i$ is adjusted mean sum of squares for factor *I*and $Adj\ MS_E$is adjusted mean sum of squares for error. The greater F_{value} shows that the variation of the parameter has a larger impact on the output performance characteristics. The degree of significance of the computed F_{value} can be determined by looking up F-tables. Also, the percentage contribution ρis defined as Equation 4:

$$\rho(\%)=\frac{Adj\ SS_i\text{-}DF_i \times Adj\ MS_E}{SS_T}\times 100 \qquad (4)$$

WhereSS_T,$Adj\ SS_i$ and DF_i are the total sum of square, adjusted sum of squares factor *i* and degree of freedom for factor *i*, respectively. A small variation will have a large influence on the output of the factors which have high percent contribution (Yang and Tarng, 1998; Choi and Kang, 2010). Referring to Table 5, controllable factors can be ranked as: B, C and A. Thus, the most significant factor affecting the CS was the particle size (38.95%), the secondranking factor was temperature(9.17%) and third ranking factor was diameter of pellet (7.11%).

3.2Verification

The drawn results during the Taguchi analysis are verified in next step. The response of the optimalparameters is also predicted. The predicted S/N ratio for the optimal combination of parameters is Equation 5:

$$\hat{\eta}=\eta_m+\sum_{i=1}^{p}\left(\bar{\eta}_i-\eta_m\right) \qquad (5)$$

Where $\bar{\eta}_i$ is the mean of S/N ratio at the optimum control factor settings η_m is total mean of S/N ratio and *p* represents the number of control factors.

Table 6 shows the results of the confirmation experiment for CS of pellet.Increase of the S/N ratio from the initial parameters (A1,B2,C1,D1) to the optimal parameters (A2,B1,C3,D2) was 2.3 dB, which means that the CS of pellet is improved1.3 times.

Table 6Results of the confirmation experiment for CS of pellet

	initial Parameters	Optimal parameters (A2,B1,C3,D2)	
	(A1,B2,C1,D1)	Prediction	Experiment
CS of pellet(N)	100.15	125.365	130.45
S/N ratio (dB)	40.0130	41.9784	42.3089

4 Conclusions

In this paper, optimization of the compression strength of compost pelletusingTaguchimethod is presented. The Taguchi method with analysisof S/N ratio was used to obtain the optimal conditions. The process starts with identifying the control factors and their levels and then setting up the orthogonal arrays for experiments. A L36 orthogonal arrays table was constructed for the controllable factors.The S/N ratios were calculated and optimal parameters combination for the CS of pelletis determined. After conducting the Analysis of variance, the particle size was determined as the most important factor affecting CS of pellet and theeffect of air velocity was not statisticallysignificant. The experimental results confirm the validity of the used Taguchi method to improve the CS of pellet. Maximum CS of pellet was observed as 130.45 N.Using the optimum settings as compared with the initial, the S/N ratio improves by 2.3 dB, which corresponds to an increase of 1.3 times in the CS of pellet.

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