OPTIMIZING SOME DESIGN PARAMETERS TO BUILD A MACHINE MODEL TO SEPARATE PLASTIC BAGS FROM HOUSEHOLD WASTE

TỐI ƯU HÓA MỘT SỐ THÔNG SỐ THIẾT KẾ MÔ HÌNH MÁY TÁCH TÚI NILON TỪ RÁC THẢI SINH HOẠT

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ABSTRACT

Plastic bags in household waste are one of the factors causing serious environmental pollution. The problem of classifying plastic bags from household waste for recycling and separate treatment is an urgent need today. This paper introduces a study on optimizing some design parameters for building a model of a machine to separate plastic bags from domestic waste. The objective of this model is to obtain the largest percentage of plastic bags and the smallest percentage of impurities in them. The simulation tool in SolidWork is used in this study to determine the appropriate structure and size of the drum - an important component of the machine. The survey experiments performed allow to determine the structural and technological parameters that have the greatest impact on the machine's working efficiency. These parameters are the air flow pressure of the pneumatic nozzle (p), the horizontal distance between the pneumatic nozzle and the center of the drum (dX), and the height of the air nozzle relative to the center of the drum (dH). The study is carried out with a 3-variable, 3-level Taguchi experimental design. Gray relational analysis (GRA) combined with Taguchi technique is applied for multi-object optimization in order to achieve the largest percentage of plastic bags and the smallest percentage of impurities at the same time. The optimal set of parameters (p, dX, dH) is determined to achieve the best working efficiency of the machine.

Keywords: *Plastic bags, household waste, Taguchi, ANOVA, Gray relational analysis (GRA).*

TÓM TẮT

Túi nilon trong rác thải sinh hoạt gia đình là một trong các nguyên nhân chính gây ra ô nhiễm môi trường. Vấn đề phân tách túi nilon khỏi rác thải sinh hoạt để tái chế là một yêu cầu cấp bách hiện nay. Bài báo này giới thiệu một nghiên cứu về tối ưu hóa các thông số thiết kế cho chế tạo một mô hình máy phân tách túi nilon từ rác thải sinh hoạt. Chỉ tiêu đầu ra của mô hình máy là phân tách được tỷ lệ túi nilon lớn nhất và tỷ lệ các thành phần khác từ rác thải sinh hoạt là nhỏ nhất. Công cụ mô phỏng của SolidWork được sử dụng để xác định kết cấu và kích thước tang quay - một chi tiết quan trọng của máy phân loại rác. Các thực nghiệm khảo sát đã được tiến hành cho phép xác định các thông số công nghệ và thông số kết cấu ảnh hưởng lớn nhất đến hiệu quả làm việc của máy. Các thông số này là áp suất của vòi phun (p), khoảng cách theo phương ngang giữa vòi phun khí và tâm quay của tang (dX), và chiều cao từ vòi phun đến tâm quay tang (dH). Nghiên cứu đã được triển khai thực hiện theo thiết kế Taguchi 3 biến, 3 mức. Phân tích quan hệ xám (GRA) kết hợp với kỹ thuật Taguchi được áp dụng cho tối ưu hóa đa mục tiêu nhằm đạt được tỷ lệ phân loại túi nilon lớn nhất, tỷ lệ các thành phần khác trong rác thải sinh hoạt là nhỏ nhất. Bộ thông số tối ưu (p, dX, dH) được xác định để đạt được hiệu suất làm việc của máy là tốt nhất.

Từ khóa: *Túi ni lon, rác thải sinh hoạt, Taguchi, phân tích phương sai (ANOVA), Phân tích quan hệ xám (GRA).*

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1. INTRODUCTION

Every day, people use a large number of plastic bags to pack goods, items, food, ... Remarkably, only a very small number of plastic bags are collected and reused. A large number of plastic bags are discharged into the environment along with household waste. These plastic bags, if not separated from household waste for recycling and treatment, will cause serious environmental pollution. In [1], The authors analyze the meaning of separating plastic waste after collection and economic efficiency compared to sorting plastic waste at home. In [2] the authors conducted an investigation into the recycling stages of household plastic processing such as classification, cleaning, decomposition and recycling based on information collected from available documents.

Several companies have brought to market a number of technological solutions and equipment to separate plastic bags from waste to solve this problem. Impact Air System [3] has provided the market with a number of separation technology solutions, including Drum Separator devices, which is used for separating a mixed stream of material into heavy and light components, using a forward upward facing air knife nozzle mounted at the end of a material in-feed conveyor. This device allows to separate plastic bags from inorganic waste without getting wet and sticky. TOMRA Systems [4] has also provided the market an intelligent sorting device, the AUTOSORT SPEEDAIR. The garbage mixture is fed into the machine from the feeding conveyor system. Pneumatic nozzles with sensors will open compressed air when a plastic bag passes through. The Sistema Aspiración de Plástico Film of BIANNA [5] uses large cross-sectional pneumatic nozzles. The air flow blown during the garbage separation process will be recovered and reused. The common feature of the above devices is that they all use high-pressure airflow to classify. Research publications in this area are quite limited. Moreover, domestic waste in Hanoi as well as other localities in Vietnam also has its own characteristics. Therefore, it is necessary to have statistical studies on domestic waste in Vietnam and propose solutions to separate plastic bags from this domestic waste. Based on the above needs, the model of a machine to separate plastic bags from domestic waste has been researched and developed at the BKAPEMA Technology Company Limited. This machine model works based on the general principle of garbage sorters already in the world, which is to use high-pressure compressed air to sort. This paper introduces the principle, structure, and basic design parameters of the machine model. The simulation tool in SolidWork was used to determine the appropriate structure and size of the drum - an important component of the machine. Gray relation analysis combined with Taguchi method is also applied to determine the important design parameters of the machine in order to achieve the highest percentage of classified plastic bags and the percentage of impurities in it. smallest. The design parameters to be optimized here are the distance between the compressed air nozzle to the vertical and horizontal center of drum rotation and the air flow pressure. With this set of optimal design parameters, a test machine model was built and tested, allowing the highest efficiency of separating plastic bags from household waste.

2. DESIGN A MACHINE MODEL

2.1. Operation principle and general structure

The input garbage will be continuously fed to the conveyor surface (3). Conveyor driven by electric motor (2) will move in the direction of the arrow, sending the garbage mixture through the compressed air nozzles (9). Here the mixture will be affected by the air jet provided by the air compressor (1), so it is possible to separate the light weight components as plastics bags from the mixture. Components with heavy weight will be dropped into the impurity collection bin (8). After light components such as plastic bags fly up, they will reach the drum (5). The drum (5) is driven by an electric motor (7) which rotates in a counter-clockwise direction to take the light components other than plastic bags back to the the impurity collection bin. The plastic bags will continue to fly over the drum and be collected by the plastic bag collection bin (6).

Design parameters are determined based on survey experiments to evaluate the impact of these factors on the working efficiency of the machine. They include: Air pressure: 5 - 7 (at); Number of pneumatic nozzles: 8 (pcs); Angle of inclination between the air jet and the horizontal: 350; Distance between compressed air nozzles in both vertical and horizontal directions: 110 x 140 (mm); Vertical distance between pneumatic nozzles and conveyor 90 (mm); Thickness of garbage feeding on the conveyor: 100 (mm); Conveyor speed: 3 (m/s); Drum rotation speed: 20 (rev/min); Horizontal distance between the pneumatic nozzle and the center of the drum: 1000 - 1200 ((mm); Height of the air nozzle relative to the center of the drum: 50 - 250 (mm).

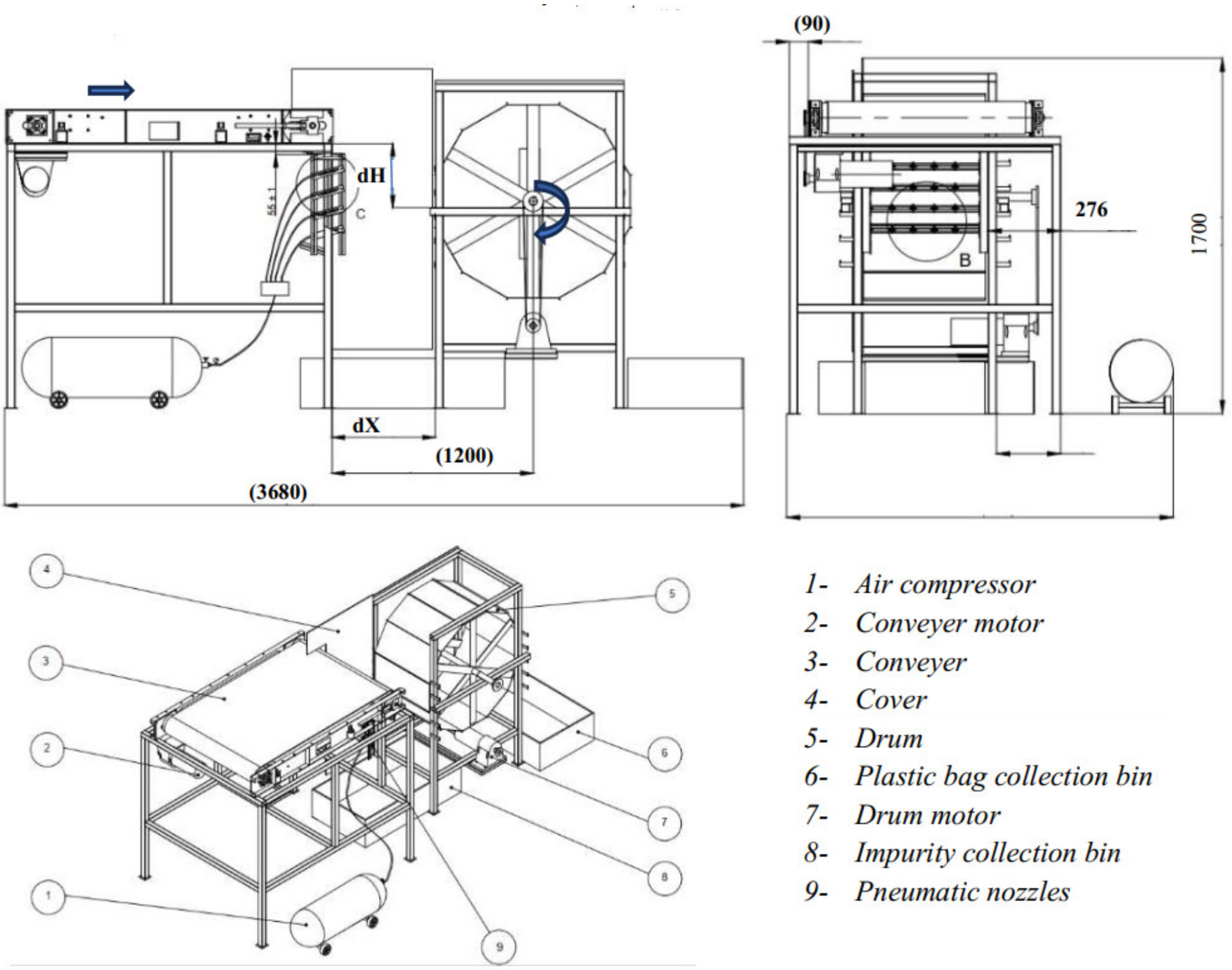

Fig. 1. General drawing of the machine model

2.2. Optimizing the size, shape and structure of the drum

The structure, shape and size of the drum are among the first important factors to be determined. The drum design solutions are presented in the diagram in Fig. 2

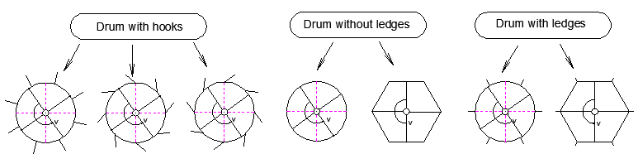

Fig. 2. Design solutions of the drum

The drum with hooks has the limitation that plastic bags as well as impurities are often trapped on the drum, reducing the efficiency of the machine. For drums without ledges as well as cylindrical drums, light impurities are usually blown out of the drum and not collected into the impurity collection bin. So, polyhedron drums with ledges that limit the above disadvantages are selected in this study. The Flow Simulation tool in SolidWork has been applied to determine the velocity field of the gas flow for different structures and drum sizes.

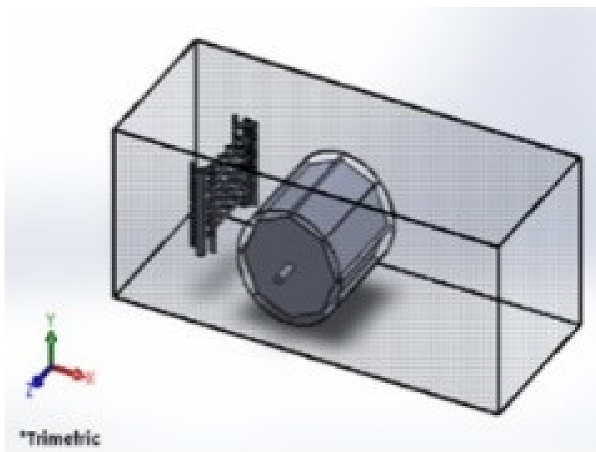

Fig. 3. Input geometric data

The larger the drum surface area with high velocity air flow, the greater the ability to separate and collect the plastic bags. From there, determine the most suitable drum size and structure. The input data is the 3D geometric model of the drum, the pneumatic nozzles, the cover (Fig. 3) and some boundary conditions presented in Section 2.1.

Simulation results show that a 12-sided drum with a diameter of 1000mm and a ledge height of 10mm is the most optimal (Fig. 4g).

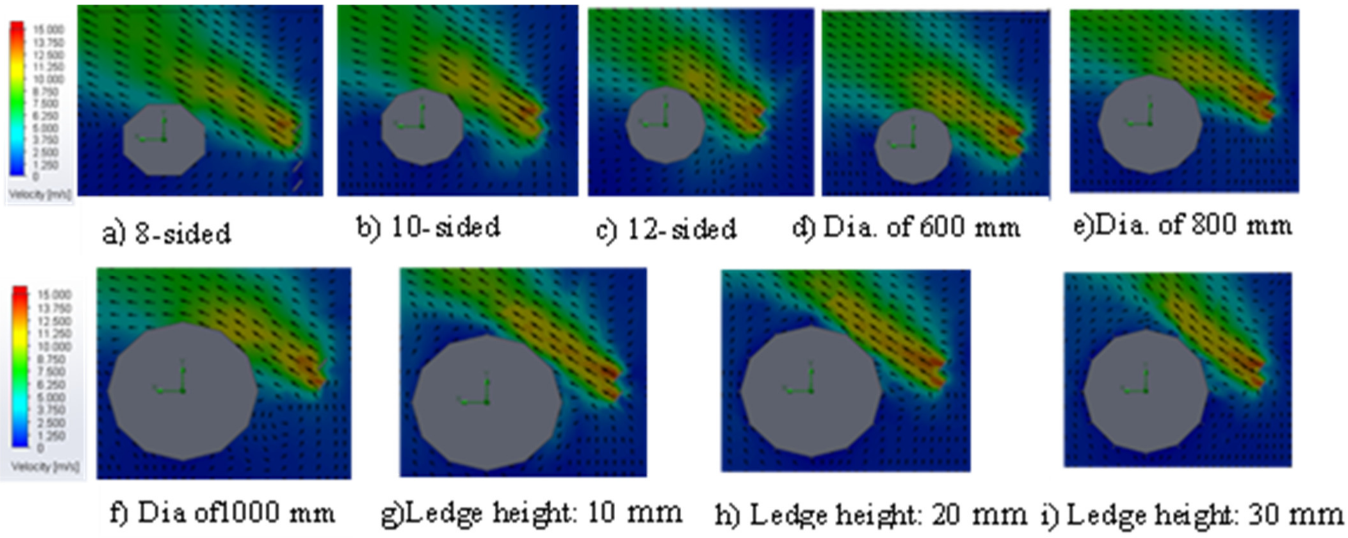

Fig. 4. Simulation results for 9 cases

3. EXPERIMENTS, RESULTS AND DISCUSSION

Table 1. Equations of Grey relational analysis and Taguchi method

In case of "larger is the better" criterion, the output responses are normalized by: $y_i^* = \frac{y_{ij} - \min(y_{ij})}{\max(y_{ij}) - \min(y_{ij})}$ (1)	In case of "smaller is the better" criterion, the output responses are normalized by: $y_i^* = \frac{\min(y_{ij}) - y_{ij}}{\max(y_{ij}) - \min(y_{ij})}$ (2)
Difference of the absolute value between $y_0(k)$ and $y_i(k)$: $\Delta_{0i}(k) = \lvert y_{0j} - y_{ij} \rvert$ (3) $\Delta_{max} = \max\begin{Bmatrix}\Delta_{0i}(k), i=1,2,...,m;\\ k=1,2,...,n\end{Bmatrix}$ (4) $\Delta_{min} = \min\begin{Bmatrix}\Delta_{0i}(k), i=1,2,...,m;\\ k=1,2,...,n\end{Bmatrix}$ (5)	Gray coefficients: $\gamma\left[y_0^*(k), y_i^*(k)\right] = \frac{(\Delta_{min} + \xi\Delta_{max})}{(\Delta_{0i}(k) + \xi\Delta_{max})};$ (6) $0 < \gamma\left[y_0^*(k), y_i^*(k)\right] < 1$
Grey Relational grade: $\Gamma(y_0^*, y_i^*) = \sum_{k=1}^{n} w_k \gamma(y_0^*(k), y_i^*(k))$ (7) $\sum_{k=1}^{n} w_k = 1$ (8)	S/N ratio in case of ""the larger, the better": $S/N = -10\lg\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$ (9)

The theoretical basis used in the empirical research here is the Taguchi method and Gray relational analysis (GRA) [6-8]. The basic formulas for determining the S/N ratio and Gray relations grade are presented in Table 1.

Experimental research was conducted on a machine model designed and manufactured with input materials of inorganic household waste including plastic bags, cardboard, paper, cardboard, metal cans, plastic, wood, fabric... with dimensions no larger than 300mm.The experiment is designed according to the orthogonal array L9. Three input variables are air pressure (p), horizontal distance between center of drum and pneumatic nozzles (dX), height of the pneumatic nozzle relative to the center of the drum (dH). Each variable has three levels as shown in Table 2. The output response of the experiment is the percentage (Per1) of plastic bag weight compared to the input garbage volume and the percentage (Per2) of impurities in it. The goal here is to find the optimal set of parameters to achieve the maximum percentage of plastic bags and the smallest percentage of impurities simultaneously. According GRA theory, all individual performance characteristics can be expressed by a single criterion such as the grade.

Table 2. Experimental layout using the orthogonal array Taguchi L9

No.	Design parameters			Percentage of plastics bags Per1. (%)	Percentage of impurities Per2 (%)
	Air pressure p (at)	Distance dX (mm)	Hight dH (mm)		
1	5	1000	50	66.5	8.8
2	5	1100	150	83.3	6.9
3	5	1200	250	90	5.7
4	6	1000	150	87	12.3

5	6	1100	50	97.1	9.61
6	6	1200	250	65.6	9.23
7	7	1000	150	99.4	16.9
8	7	1100	250	75.5	12.3
9	7	1200	50	82	13.8

Therefore, it is possible to replace the multi-objective optimization problem with the optimization problem for one-object as grade. The grade is considered as the common criterion for both the percentage of plastic bags (Per1) and the percentage of impurities ((Per2). Firstly, the data of two target functions Per1 and Per2 is normalized by using equations (1), (2). Normalized data are recorded in columns 2 and 3 of Table 3. The deviation sequences between reference sequences and comparable sequences are calculated by (3). The results are shown in column 4 and column 5. The gray coefficients for each experiment are determined by using (4), (5), (6) and are shown in column 6, column 7. Grey Relational grades are defined by formula (7), (8) and recorded in column 8. The S/N ratio of Grade for each run is defined by using equation (9) and recorded in last column.

Table 3. Results of grey relational analysis and S/N_{Grade}

Runs	Normalization		Deviation Sequence		GR. coefficient		Grade	S/N_{Grade}
	Per1	Per2	Per1	Per2	Per1	Per2		
1	0	0.7232	1	0.2768	0.3333	0.6437	0.4885	-6.2226
2	0.5106	0.8929	0.4894	0.1071	0.5054	0.8235	0.6644	-3.5067
3	0.7143	1	0.2857	0	0.6364	1	0.8182	-1.7100
4	0.6231	0.4107	0.3769	0.5893	0.5702	0.4590	0.5146	-5.7150
5	0.9301	0.6509	0.0699	0.3491	0.8773	0.5889	0.7331	-2.680
6	0.0274	0.6848	1.0273	0.3152	0.3274	0.6134	0.4704	-6.4964
7	1	0	0	1	1	0.3333	0.6667	-3.5218
8	0.2736	0.4107	0.7264	0.5893	0.4077	0.4590	0.4334	-7.1980
9	0.4711	0.2768	0.5289	0.7232	0.4860	0.4088	0.4474	-6.9216

Main effects of p, dX and dH to the grade are shown in Fig. 5. From that, the optimal parameter set for the highest grade is defined. With the air pressure of 5at, the horizontal distance (dX) of 1000mm and the hight (dH) of 250mm we will have the largest percentage of plastic bags and the smallest percentage of impurities at the same time.

The machine model has been built with the optimized drum and this set of parameters (Fig. 6) and has been tested to achieve the separation capacity of plastic bags from domestic waste of 2tons/h.

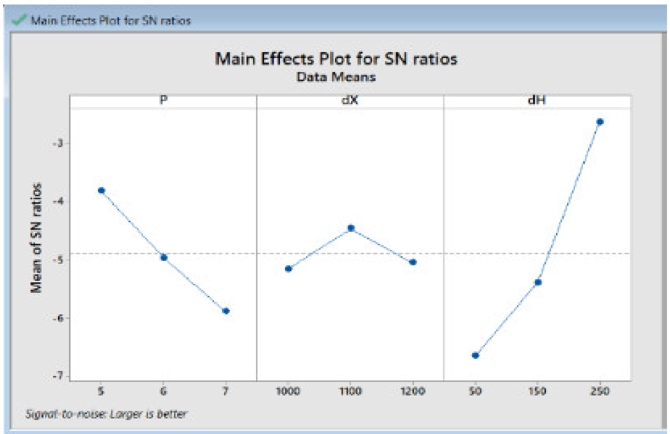

Fig. 5. Main effects of parameters on the grades

Fig. 6. Picture of the machine model

4. CONCLUSIONS

This paper presents a study on optimizing design of a machine to separate plastic bags from household waste. The simulation tools in SolidWorks have been applied to determine the shape, structure, and dimensions of the drum, an important part of the machine. Domestic waste data in Hanoi has been sampled and used as input data for the machine for experimental implementation. This machine has been built, tested and surveyed with this household waste to determine the most important design parameters that need to be optimized. These parameters are the air flow pressure of the pneumatic nozzle (p), the horizontal distance between the pneumatic nozzle and the center of the drum (dX), and the height of the air nozzle relative to the center of the drum (dH). GRA and Taguchi methods are used in multi-objective optimization to get the best machine performance. The optimal set of parameters (p, dX, dH) has been determined to achieve the maximum percentage of plastic bags separated from domestic waste and the smallest percentage of impurities in it.

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