Sigma J Eng & Nat Sci 37 (4), 2019, 1075-1086

Sigma Journal of Engineering and Natural Sciences
Sigma Mühendislik ve Fen Bilimleri Dergisi

Research Article

ANALYSIS OF MAGNETIC PERFORMANCE FOR MAGNETIZED PACKED AND UNPACKED BED

Zehra YILDIZ*[1]

[1]*Department of Energy Systems Engineering, Faculty of Technology, Tarsus University, MERSİN;*
ORCID: 0000-0003-1304-4857

Received: 22.05.2019 Revised: 28.08.2019 Accepted: 21.09.2019

ABSTRACT

In this study, optimal levels of the magnetized packed bed design parameters on the magnetic performance have been obtained by using Taguchi experimental design approach. Given the associated the parameters such as the diameter of the bed elements (d), magnetic strength (H), and the bed length (L), the results estimate the effects on the magnetizing performance of the magnetized packed bed. The analysis of Taguchi method reveals that, magnetic strength and the diameter of the bed elements have significantly affected the magnetizing performance of the magnetized packed bed. Data obtained from Taguchi experimental design on the magnetic intensity of the bed resulted in the optimized process conditions of 280 kA/m as the magnetic strength, the bed length of 6 cm and the diameter of the bed elements 8 mm. Maximum magnetic intensity 0.606 T was obtained at the optimized conditions in the bed parameters. In addition, magnetic intensity values that called as magnetic performance values are corrected by the uncertainty analyses. Magnetic intensity in the magnetized packed bed adjusted with ASME PTC 19.1 uncertainty analysis methods. Although some partial fluctuations in the magnetic intensity are available as long as the bed, the general variation characteristics of magnetic characteristic property of the bed is constant.
Keywords: Magnetized packed bed, uncertain analysis, Taguchi method, magnetic filter, magnetic separation.

1. INTRODUCTION

Magnetic filtration can be used to magnetically clean for aerosol systems that are contained from poor paramagnetic to ferromagnetic particles. The magnetic filtration is both economic and ecologic process because the process only needs low external magnetic intensity such as 0.5 T. Magnetic filter elements are different other than filter elements. Magnetic filter elements are magnetic materials such as balls, rods, wools, wires, chips. The high magnetic field gradient is produced around the touching points of these materials, a colloidal or suspension system is cleaned by capturing on magnetic touching points when any dispersed magnetic impurities is passed through the filter. Magnetic filters are especially used in many industry for the separation of corrosion products from carrier media such as liquids and gases. Because corrosion products contain magnetic particulates from the poor paramagnetic to the ferromagnetic property. Magnetic filtration performance firstly depends on magnetic characteristics of the bed.

* Corresponding Author: e-mail: zyildiz35@hotmail.com, tel: (324) 627 48 04 / 126

Magnetized packed bed constructed from magnetic filter elements are their magnetizing characteristics under magnetic field [1-7].

The magnetizing characteristics of the filter were modeled as a function of the independent variables classified as the magnetic strength, the bed length and size of the bed elements. The magnetizing characteristics of the magnetized packed bed can be especially given as the B-H curves. Magnetized packed bed performance can be given as magnetic intensity. B is magnetic intensity. H is the magnetic strength. H is one of the most important factors on the effectiveness and the operational cost [9-11]. The studies were carried out mainly at low values of the magnetic strength ($H \leq 50$ kA/m). In particular, it is not sufficient to investigate the change in magnetic properties of the beds formed that is constructed magnetic granules depending on the change of bed porosity and the large values of magnetic strength ($H \geq 100$ kA/m). This adversely affects the design and optimal control of the devices and processes to which such bearings are applied [4]. For this reason, this study was carried out at high values of the magnetic strength ($H \geq 175$ kA/m).

It is most important in the bed parameters that are an effect on B-H relation of the bed; size of the bed elements and filter length. In this study, the B-H relation of the unpacked bed and the packed bed is investigated. It is used stainless steel balls for the packed bed as the packing elements. The results give as the B-H curve of the beds. The most important properties affecting the B-H relation of the beds are length of bed, size of the bed elements, kinds of the bed elements and porosity fraction factor of the bed. B-H curve is useful to estimate the difference of the magnetic intensity, since this variation affects the bed parameters. In addition, the magnetic intensity was determined by taking the average of three different values. Uncertainties in the measurement of the magnetic intensity set by the uncertainty analysis methods and the measured magnetic intensity values have been corrected according to the equation. Thus, B-H curves that is given magnetic characteristic property of the bed are more accurately drawn.

The evaluation of the results obtained from the magnetic intensity measurements allowed investigating the effect of the variation of the magnetized packed bed parameters. Affect of the magnetized packed bed parameters on the magnetic performance of the bed is investigated by using Taguchi Method. It is powerful tools that have the abilities to identify relationships from the data. The method is given the information about the optimum process parameters using experimental methods. In this method, the optimal levels of the bed parameters design experimentally can be estimated. The method can be optimized with less number of experiments. The experimental results statistically is based on the analysis of variance (ANOVA) on Taguchi method. ANOVA and main effect plots were prepared to identify the optimum bed parameters. Orthogonal arrays (L9) were used to design the experiment and signal-to-noise ratio method was utilized to analyze the data [10-14].

In this article, the magnetic intensity determined effect of three different parameters the diameter of the bed elements (d), the magnetic strength (H), and the bed length (L) on the magnetized packed bed. The aim of this study was to determine the optimum bed design parameters levels for maximum the magnetic intensity by using Taguchi method. The evaluation of the data obtained from the experiments resulted by Taguchi Method allowed to investigate the effect of the variation of the parameter design on the magnetic performance of the bed.

2. EXPERIMENTAL METHOD

It is used the bed that is a rust proof case with dimensions of 3cmx3cmx10cm and are consisted of non Magnetic filter body on the experimental studies. It is used rust proof steel balls of various diameters (6 mm, 8 mm and 12 mm) as the bed elements. High intensity wet magnetic separator (DC; 0-220V; 0-20A) used to external magnetic field as shown figure 1. The magnetic intensity measurements at the different points along the bed determined according to Taguchi experimental design are evaluated using GM 05 Gauss meter.

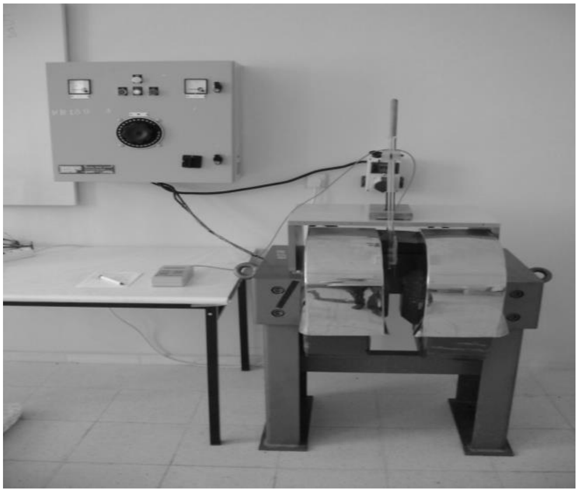

Figure 1. Magnetic separator system

Determination of the magnetic intensity in the magnetized packed bed is connected to the measurement device only. Measurements might have more or less error where in the difference between the true values with the measured value due to the device vibration. It can be caused to read out from the line along which crushing of the plate of the probe by applying the magnetic field. The variations of the magnetic intensity in air space in the axial direction was tried to determine. Three different values are measured to determine truly the magnetic intensity values corrected by ASME PTC 19.1 uncertainty analysis methods for B(H) and B(L) curves.

3. RESULTS AND DISCUSSIONS

3.1. Influence of the Bed Parameter on the Magnetic Intensity

The magnetization characteristics of the magnetized packed bed depend on many factors. Bed porosity is one of characteristics that affect the magnetic properties of the bed elements; it is varied with the diameter of the steel ball used as the bed element. Therefore, 6 mm, 8 mm and 12 mm diameter steel balls formed from three bed magnetization properties were investigated. The magnetic intensity measured values corrected after calculating uncertainty and graphs were plotted using this data. The variations of the magnetic field induction in air space in the axial direction are shown. Uncertainties in the measurement of the magnetic intensity ASME PTC 19.1 set by the 2005 uncertainty analysis methods and the measured magnetic intensity values have been corrected according to the equation. *u* refers to as the concepts ratio of standard deviation to the square root of number of repeated measurements [15].

The magnetic intensities are measured in air space in the axial direction in the magnetized unpacked bed. The variations of the magnetic intensity are shown in the figure 2-3. Homogeneous distribution can be clearly seen in fig. 1 and 2. It was found that the magnetic field intensity values at four different external magnetic field intensity values at different filter lengths were maximum in the 4-6 cm filter zone corresponding to the middle zone of the filter. On the other hand, it is observed that the values of the external magnetic field density are lower because the element is less tangent in the filter input and output regions. For this reason, it was concluded that the measurements to be made at the center of the bed would be more appropriate. On the other hand, the magnetic properties of the unfilled bed seem to be increased by the magnetic field strength.

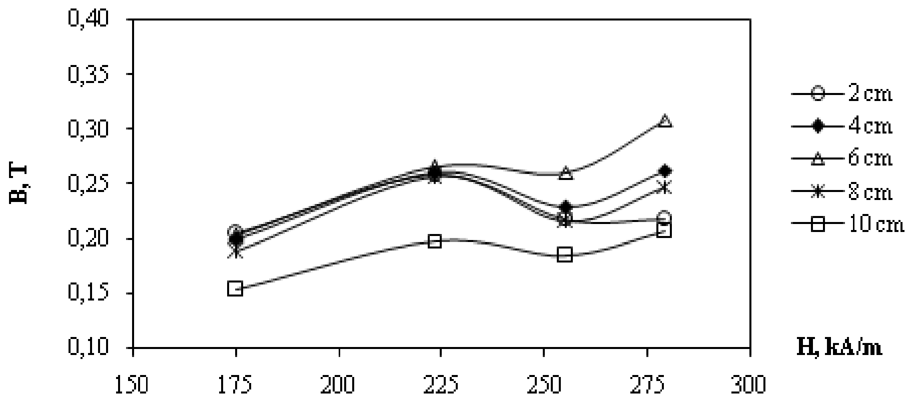

Figure 2. The average magnetizing curve of the magnetized unpacked bed

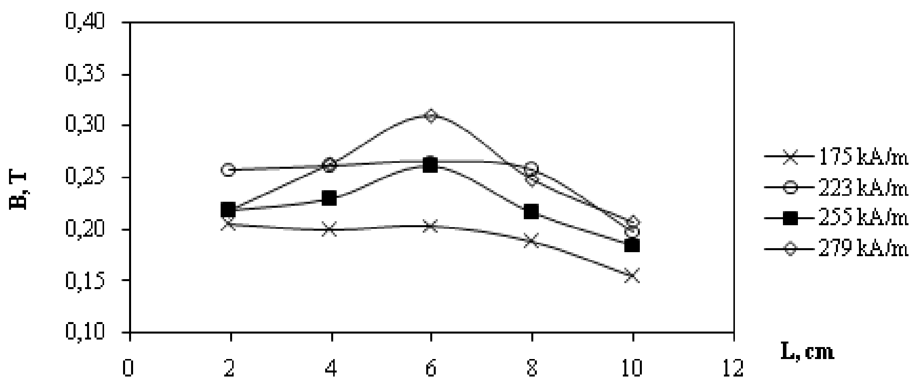

Figure 3. The magnetic field intensity profiles in the axial direction of the magnetized unpacked bed

Different the lengths of the bed at different magnetic strength with the magnetic field variation curves for the bed element diameter B (L) as seen figures 5, 7 and 9 is given. Magnetization curves B (H) is given by figures 4, 6 and 8. The bed element of the magnetization curve as a 6 mm diameter of the bed formed from the ball is shown in Figure 4. B (H) curve can be understood from the bed magnetic show that magnetic intensity, as shown in the figure, the magnetic strength increased up to 279 kA/m.

The magnetic intensity is higher in the bed length of 2-6 cm as seen from figure 5. The magnetic intensity is no more than 0.631 T. Because the filter bed increases with increasing porosity of the bed element diameter decreases the magnetic intensity. Because touch contact areas are decreased with the number of balls thus formed around the high gradient magnetic field is reduced.

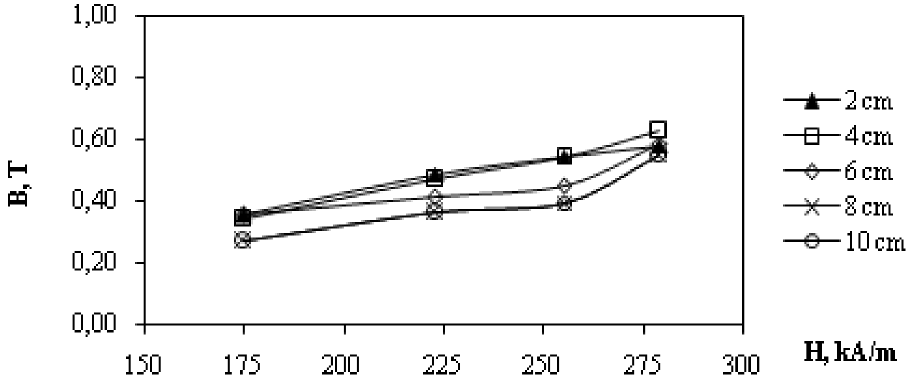

Figure 4. The average magnetizing curve of the magnetized bed (d=6 mm)

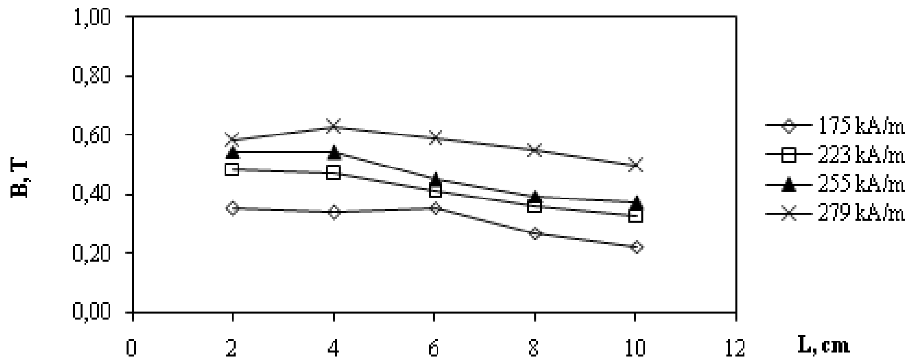

Figure 5. The magnetic induction field profiles of the magnetized bed (d=6 mm)

The magnetization curve B (H) of the magnetized packed bed formed from 8 mm steel ball is showed in figure 6. The magnetic intensity as shown in the figure, the magnetic strength reaches the magnetic saturation of the bed 225 kA/m, then no significant change.

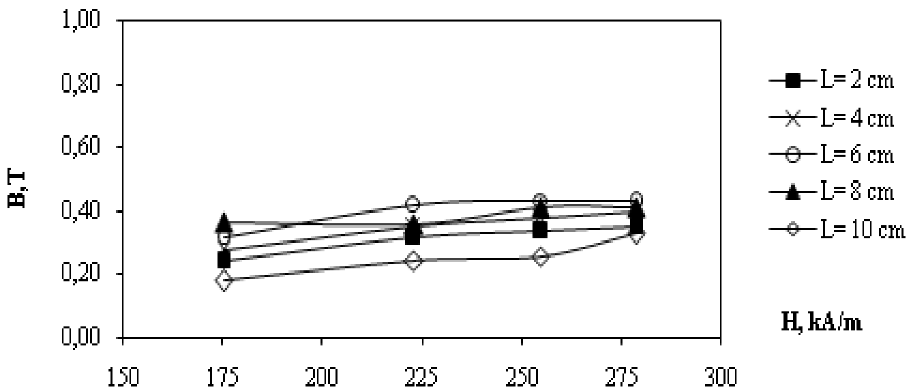

Figure 6. The average magnetizing curve of the magnetized bed (d=8 mm)

The magnetic intensity as shown in Figure 7, the maximum intensity value in the bed length 7 cm. Magnetic intensity was decreased the bed length more than 7 cm.

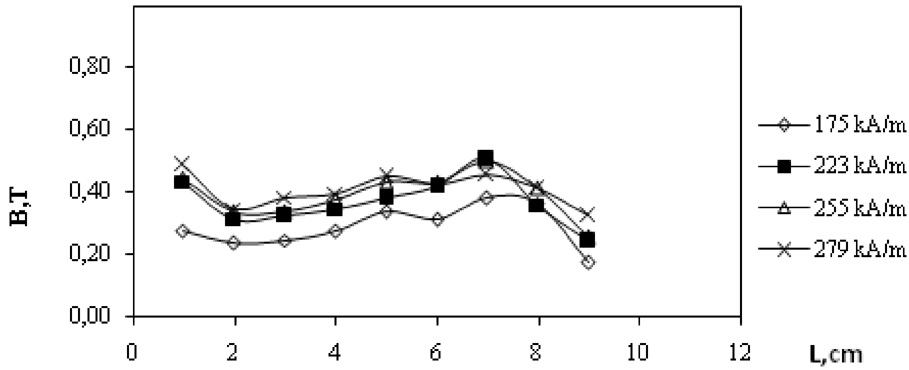

Figure 7. The magnetic induction field profiles of the magnetized bed (d=8 mm)

The magnetization curve B (H) of the magnetized packed bed formed from 12 mm steel ball is showed in figure 8. The magnetic field intensity as shown in the figure, the magnetic strength reaches the magnetic saturation of the bed 225 kA/m, then no significant change.

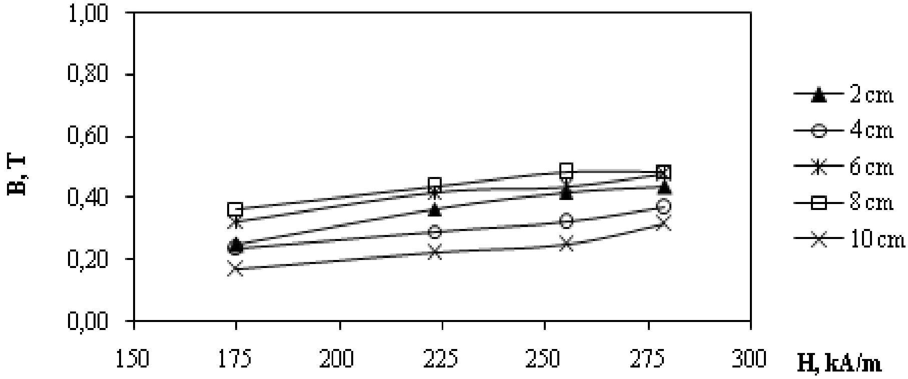

Figure 8. The average magnetizing curve of the magnetized bed (d=12 mm)

The magnetic intensity as shown in figure 9, in areas near to the bed outlet (9-10 cm) is reduced. The maximum magnetic intensity was reached in 0 .517 T value.

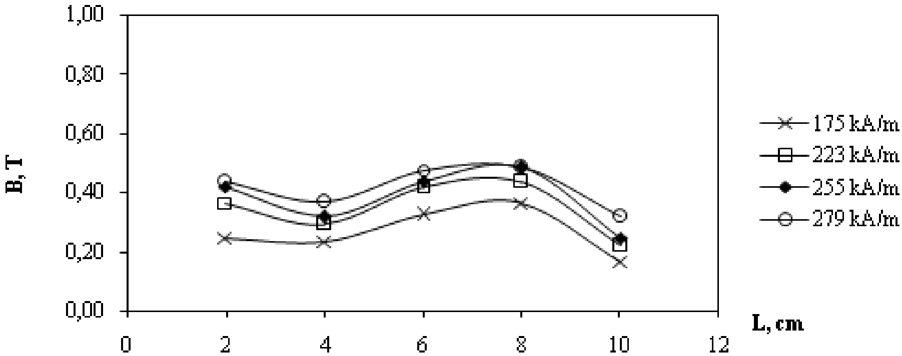

Figure 9. The magnetic induction field profiles of the magnetized bed (d=12 mm)

As a result of studies to determine the magnetic characteristics of the bed, with increasing diameter of the bed element reduced the magnetic intensity. As can be seen from the results in packed bed B(H) relationship is approximately linear. Magnetic strength was increased significantly in the magnetic intensity. Bed area with steel balls bed elements for increasing the intensity of magnetic caused by the increase in magnetic force. This takes place in all magnetized granular packed bed and varies from the porosity of the bed. These experiments to enhance the efficiency of the magnetic filtration the bed having lower porosity (ε = 0.4 to 0.6) so that used smaller diameter in steel balls it showed the need to build the bed. The magnetic particles are hold more in this area because of the higher intensity of the magnetic field in the central compartment of the filter. The magnetization saturation of the bed shows over 250 kA/m.

3.2. Analyses of the Results

3.2.1. Taguchi method

Taguchi method utilizes a special design of orthogonal arrays to optimization with only a small number of experiments. Orthogonal array (OA) is minimize the number of experiment. An orthogonal array contains factors or their interactions and the levels of various factors for a particular experimental trial.

The diameter of the bed elements, the magnetic strength and the bed length as magnetized bed parameters on the magnetic intensity were chosen as key factors on the magnetic performance of the magnetized bed. The minimum trials number is given in the orthogonal array as following

$$N_{min} = (l-1)k + 1 \quad (1)$$

where, k is number of factors and its value is 3. l is number of levels and its value is 3. Thus, N_{min} is 7 and according to Taguchi design concept L9 orthogonal array has been selected (Badkar et al. 2012). 9 experiments only are make by using L9. Three factors with three levels were considered as shown in Table 1. Taguchi method is to determined the optimum bed parameters by both to improve the process and to reduce the influence of the noise factors [10-14].

Taguchi orthogonal array experimental design was used for optimization of the bed parameters. ANOVA performed to estimate the impact of each parameter. The S/N ratio approach was used for the magnetic intensity.

The each level of the parameter is calculated based on larger-the-better corresponds to better quality characteristics for magnetic intensity. Taguchi method are not sensitive to the variation. Affect of control factor on quality characteristic is performed to see which process parameter is statistically significant.

The lower and upper limits of the magnetic strength which was applied in filtration matrices in our experiments were selected as ranging from 175 to 280 kA/m. The lower limit was adopted in consideration with the fact that particles are weakly captured with lower magnetic strength. The upper limit of the magnetic strength is greater than 250 kA/m due to magnetic saturation of the bed. Preliminary experiments revealed that the magnetic intensity were too low for the bed lengths shorter than 2 cm and filter pores were saturated with the captured particles when the length was above 6 cm. The lower limit for the diameter of the bed element was taken as smallest available 6 mm, because the filter clogs due to a pressure drop when this diameter is smaller than 3 mm. The upper limit was chosen as 12 mm although the magnetic intensity might decrease at this level.

In this study, the diameter of the bed elements, the magnetic strength and the bed length were considered in three levels to determine the optimum process parameters. Taguchi method was applied by using the Design-Expert 6.1 (DX6). The diameter of the bed elements were selected as 6:8:12; the magnetic field strength was selected as 175:225:280 kA/m and the bed length was 2:4:6 cm in three levels. The used parameters and levels are presented in Table 1.

Table 1. Variable Factor Levels

Factors	**Level 1**	**Level 2**	**Level 3**
Diameter of the bed elements, d (mm)	6	8	12
Magnetic field strength, H (kA/m)	175	225	280
Bed length, L (cm)	2	4	6

The level numbers of 1, 2 and 3 are the lowest, mid and highest levels, respectively. L_9 orthogonal array that have to be considered for performance of experiments in 9 runs. L_9 consist of three parameters in three levels mean. L_9 is given in Table 2.

Table 2. The Layout of L_9

Diameter of the bed elements d (mm)	**Magnetic field strength H (kA/m)**	**Bed length L (cm)**
1	1	1
1	2	2
1	3	3
2	1	2
2	2	3
2	3	1
3	1	3
3	2	1
3	3	2

The performance of the process is distinguished both design and noise factors. The S/N ratio is the performance measurement. The aim is to make products that are strong with respect to noise factors (N). N are the uncontrollable factors such as external factors, manufacturing imperfections and product deterioration. S is signal as design parameters. S/N ratio are the improvement of the quality. The S/N ratio can be classified to lower-the-better, larger-the-better and the nominal. The larger S/N means to the quality will become better. The related S/N ratio is defined by equation 2. The S/N ratio is selected as “larger the better” quality characteristics in order to maximize the magnetic intensity. Larger the better characteristic is given by:

$$\frac{S}{N} = -10\left(log\sum_{i=1}^{n}\frac{1/y_i^2}{n}\right) \quad (2)$$

where y, is the data obtained from experiments and *n* is the number of repetition [10-14,16-17].

The magnetic intensity measurements were repeated for three times. The each measurement results were given arithmetic means. The corresponded S/N ratio to a parameter in each level was ordered in each column to calculate the mean of S/N ratio. The magnetic intensity (B) and calculated S/N ratio of each experiment are presented in table 3 and 4. The maximum and minimum S/N ratios gives on these tables. The highest value of S/N ratio for a parameter was considered as optimum level of the parameter.

Table 3. L9 Orthogonal array of Taguchi and their S/N ratio value.

d (mm)	H (kA/m)	L (cm)	Response: Magnetic Intensity B (T) Trial 1	Trial 2	Trial 3	Average B (T)	S/N_i
6	175	2	0.335	0.330	0.339	0.335	-9.509
6	225	4	0.428	0.439	0.445	0.437	-7.187
6	280	6	0.565	0.551	0.568	0.561	-5.018
8	175	4	0.407	0.414	0.473	0.431	-7.362
8	225	6	0.528	0.460	0.479	0.489	-6.257
8	280	2	0.601	0.615	0.622	0.613	-4.258
12	175	6	0.335	0.339	0.343	0.339	-9.397
12	225	2	0.432	0.438	0.427	0.432	-7.285
12	280	4	0.383	0.394	0.392	0.390	-8.188

Table 4. the best design set is decided by choosing the level with the highest value for each factor. The optimum process parameter levels were d2. H3. and L3. The most effective factor on the magnetic intensity is the highest difference value. It was found with the difference value of 2.935 for the magnetic strength. The least effective factor is the lowest difference value 0.688 for the bed length of bed.

Table 4. The response table of S/N ratios

	d	**H**	**L**
Level 1	-7.238	-8.756	-7.017
Level 2	-5.959	-6.910	-7.579
Level 3	-8.290	-5.821	-6.891
Difference	2.331	2.935	0.688

3.2.2. Analysis of variance

ANOVA is a computational technique which is is performed to make out which process each parameters in terms of percent contribution on the overall response. ANOVA is required for estimating the variance of error for the effects and confidence interval of the prediction error. The ANOVA table contains the degree of freedom, sum of square, mean square, f value and contribution that is shown by table 5. The parameters with higher contribution are ranked higher in terms of importance in the experiment and also have significant effects in controlling the overall response. The same ANOVA table 5 also shows the R^2. The coefficient of determination R^2 ($0 \le R^2 \le 1$) indicates the goodness of fit for the model if R^2 are nearly equal to 1. R^2 with larger values is more desirable. The model has a high F value, low probability values (Prob > F). The probability values show the significance of each term. Since this has the highest *F* value and percentage of contribution.

ANOVA can be predicted the optimum bed parameters. It was found to be the most significant parameter for the magnetic intensity. ANOVA is applied to find out the significant factors for the chosen criterion. The result are given in Table 5. It is the most important factor with a contribution ratio of 51.9% on the magnetic strength followed by the diameter of the bed elements at 32.1 %.On comparing the percentage of contribution and ANOVA results for the magnetic strength and the diameter of the bed elements has greater influence than the bed length. The magnetic strength and the diameter of the bed elements have greater influence. Time has little effect on the bed length.

Table 5. ANOVA results for the Taguchi method for magnetic intensity

Parameter	**Sum of square**	**Degree of freedom**	**Mean square**	**F Value**	**% Contribution**
d	8.18	2	6.27	2.50	32.1
H	13.2	2	0.45	4.03	51.9
L	0.805	2	0.12	0.246	3.16
Total	25.5				
R^2=0.871					

4. CONFIRMATION EXPERIMENT

A confirmation tests are the final step of the experimental design. The test is performed by a test of the optimum factors and levels settings. The predicted value of the multiple S/N ratio at the optimum level (η_o) is calculated by following Equation [18]:

$$\eta = \eta_m + \sum_{i=1}^{j}(\eta_i - \eta_m) \tag{3}$$

where *j* is the number of factors. η_m the mean value of multiple S/N ratios in all experimental runs. and *i* are the multiple S/N ratios on the optimum factor levels.

Equation (2) can be used to predict the magnetic intensity. The S/N ratio calculated for the optimum level is as follows [16]:

$$\eta_o = \eta_m + (\eta A_2 - \eta_m) + (\eta B_3 - \eta_m) + (\eta C_3 - \eta_m) \tag{4}$$

where η_0 is the optimum S/N ratio. η_m the overall mean of S/N values. The average value of S/N at the third level of magnetic strength. the average value of S/N at the first level of diameter of the balls and is the average value of S/N at the second level of the bed length. Substituting the values of various terms in Equation (3).

$$7.162 + (-5.959-(-7.162))+(-5.821-(-7.162))+(-6.891-(-7.162)) = -4.347 \tag{5}$$

The procedure is to back-transform S/N to find the performance value expected which is equivalent to 0.606 T. Comparisons of Taguchi and experiment results the magnetic intensity values as shown in Table 6. Taguchi models can successfully predict the value during magnetic performance of the magnetic bed as shown in Table 6.

Table 6. The comparison of magnetic intensity values predicted by Taguchi method

Magnetic Intensity (T)	Taguchi method	Experimental
Initial (d1H1L1)	0.367	0.335
Optimum (d2H3L3)	0.606	0.616
Gain	0.239	0.281

The author's another study aims to response surface methodology (RSM) for predicting the magnetic intensity in the bed. The results suggest better performances by the response surface method as well as the two optimization approaches (Table 7). The optimum conditions was obtained for the magnetic intensity and the optimum magnetic strength was 407.44 kA/m. optimum filter length was 1.79 cm and optimum porosity fraction factor was 0.672. The predicted magnetic intensity was 0.852 T at the optimum conditions levels. On the other hand. if Taguchi experimental approach used the optimal process parameter levels are the diameter of the bed elements 8 mm. The magnetic strength 280 kA/m and the bed length 6 cm. The maximum magnetic intensity was 0.606 T in the optimum points. The bed length is affect the cost of the setup while the magnetic strength is affect the cost of the initial setup of the system as well.

Table 7. The comparison of magnetic intensity values predicted by optimization method

Optimization Method	The bed length (cm)	Magnetic Strength (kA/m)	Magnetic Intensity (T)
RSM	1.79	407.44	0.852
Taguchi	6	280	0.606

5. CONCLUSIONS

The application of Taguchi experimental approach has been employed to determine the best experimental set. such as the diameter of the bed elements. magnetic field strength and the bed length. for simultaneously maximizing the magnetic intensity. The experiments were planned as L9 orthogonal array. The optimal process parameter levels were obtained to only 9 experiments. The contribution of each factor on the performances was determined through ANOVA. S/N ratio and ANOVA. the following conclusions are selected within the ranges of the process parameters. The optimal process parameter levels are the diameter of the bed elements 8 mm. magnetic strength 280 kA/m and the bed length 6 cm. The validity experiment was carried out this condition and the same results were obtained. It is concluded that the yield of magnetic intensity maximized to 0.616 T under the process parameter levels. This results show that to enhance the efficiency of the magnetized packed bed that are constructed from the mixture of the magnetic ball of various sizes. having lower diameter of the bed elements so that filling occurs from smaller diameter (6-8 mm) in steel balls it showed the need to build the bed. The magnetic particles because of the higher intensity of the magnetic field in the central compartment of the bed (0.6-0.7 T) are hold more in this area.

REFERENCES

[1] Hristov. J. Y.. "Fluidization of ferromagnetic particles in a magnetic field Part 1: the effect of field line orientation on bed stability". *Powder Technology*. 87: 59-66. (1996).

[2] Abbasov. T.. "Magnetic filtration with magnetized granular beds: Basic principles and filter performance". *China Particuology*. 5: 71–83. (2007)

[3] Sandulyak A. Sandulyak A. Ershova V. Polismakova M. Sandulyak D.. "Use of the magnetic test-filter for magnetic control of ferroimpurities of fuels. oils. and other liquids

(phenomenological and physical models)". *Journal of Magnetism and Magnetic Materials*. 426. 714–720. (2017)

[4] Karadağ T.. Yildiz Z.. Abbasov T.. Sarımeşeli A.. "Estimation of magnetization properties of the ferromagnetic polly granular beds". *J Dispersion Science Technology.* 31(6): 826-830. (2010)

[5] Karadag T., Bakir H. G., "Modeling of particle-capture mechanism of axial magnetic filter in bounded flow field with variable viscosity", *Particulate Science and Technology* (2018).

[6] Huang S., Park H., Park Y. K., Jo Y. M., "Dynamic Trajectory and Capture of Fine Dust by Magnetic Mesh Filters Based on a Particle Velocity Model", Aerosol Science and Technology, 49:633–642 (2015).

[7] Zengb H., Lia Y., Xuc F., Jiangb H., Zhangb W., "Feasibility of turbidity removal by high-gradient superconducting magnetic separation", *Environmental Technology*, 36:19, 2495–2501 (2015).

[8] Yıldız Z.. Yuceer M.. Abbasov T.. "Performance prediction of the magnetic packed bed using response surface methodology". *Particulate Science and Technology*. 31:181-185. (2013).

[9] Sandulyak D.A.. Snedkov A.B.. Sandulyak A.A.. Sandulyak A.V.. Ablaeva A.E.. "Functional Properties of Granular and Quasi-granular Ferromagnetic Material (Filter-matrix) in Magnetophoresis Technology". *Processing of the 4th International Conference on Materials Engineering for Advanced Technologies (ICMEAT).* . 663-665. (2015).

[10] Ross P.. "Taguchi techniques for quality engineering-loss function. orthogonal experiments. parameter and tolerance design". New-York: McGraw-Hill. (1998).

[11] Bendell A. Disney J. Pridmore W. A.. "Taguchi methods application in world application: industries. productivity. improvement and case study". New York: IFS. (1989).

[12] Badkar D.. Pandey K.. Buvanashekaran G.. "Multıperformance optımızatıon of tensıle strength and heat ınput of laser transformatıon hardenıng of commercıally pure tıtanıum usıng taguchı methodology and utility concept". *Advances in Production Engineering & Management*. 7 (3): 165-176. (2012)

[13] Akhgar B.N.. Pazouki M.. Ranjhar M.. Hosseinnia A.. Salarian R.. "Application of Taguchi method for optimization of syntheticrutile nano powder preparation from ilmenite concentrate". *Chemical Engineering Research and Design*. 90: 220-228. (2012)

[14] Uysal A.. Altan M.. Altan E.. "Effects of cutting parameters on tool wear in drilling of polymer composite by Taguchi method". *Int. J Adv Manuf Technol* 58. 915–921. (2012).

[15] The Specialist Committee on Uncertainty Analysis. Final Report and Recommendations to the 25th ITTC. 2: 433-471. (2008).

[16] Bhagat T. C.. Payal H.S.. Sethi B.L.. "Optimizations of EDM process parameters for surface roughness machining die steel using copper tungsten electrode by adopting Taguchi array design". *Indian Journal of Science and Technology* (5)10:428- 3432. (2012).

[17] Baligidad S. M. , Chandrasekhar U., Elangovan K., Shankar S., "Taguchi's Approach: Design optimization of process parameters in selective inhibition sintering" *Materials Today: Proceedings,* 5:2, 4778-4786 (2018)

[18] Canbolat A. S., Bademlioglu A. H., Arslanoglu N., Kaynakli O., "Performance optimization of absorption refrigeration systems using Taguchi ANOVA and Grey Relational Analysis methods", *Journal of Cleaner Production*,229:874-885. (2019)

[19] Fatoba O. S.. Akanji O. L., Aasa A. S., "Optimization of carburized uns g10170 steel process parameters using taguchi approach and response surface model (RSM)". *Journal of Minerals and Materials Characterization and Engineering*. 2: 566-578. (2014).