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Study Of Particles Flow Over Industrial Wobbler Type Feeder Using Discrete Element Method

Endüstriyel Wobbler Tipi Besleyici Üzerinden Parçacık Akışının Ayrık Elemanlar Yöntemi İle İncelenmesi

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ABSTRACT

Wobbler feeders are generally used to feed coarse material to the primary crusher in the mine and aggregate applications. In the operation, finer particles are also screened through the spaces among rollers and wobbling of the rocks through the roller cause impact and rubbing effect that helps to move undesired particle over batches. Motion of the materials on the feeder depends on design parameters such as roller size, rotation speed, spacing etc. and also gradation of the bulk material that fed into the feeder. The performance investigation of the feeder heavily relies on experimental studies due to complex motion of the material on the feeder as well as particle interaction in the batch. Discrete Element Method is a method that used to compute motion of large number of particles in a granular flow and it is widely accepted as an effective method in the rock mechanics. In this study, DEM is used to investigate the performance of a wobbler feeder. The feeder is designed and simulated for different parameters such as spacing, roller speed, particle shape and gradation in The Rocky DEM software. The particle velocities and trajectories were determined, and particle resident times were calculated to investigate the efficiency of the feeder for different disc configurations.

Keywords: Discrete element method, particle shape, wobbler feeder

ÖZ

Wobbler besleyiciler genellikle maden ve agrega uygulamalarında kaba malzemeyi birincil kırıcıya beslemek için kullanılır. Operasyonda, silindirler arasındaki boşluklardan daha ince parçacıklar da elenir ve kayaların silindir boyunca sallanması darbe ve sürtünme etkisine neden olarak istenmeyen parçacıkların yığınlar üzerinde hareket etmesine yardımcı olur. Malzemelerin besleyici üzerindeki hareketi, silindir boyutu, dönüş hızı, boşluk vb. gibi tasarım parametrelerine ve ayrıca besleyiciye beslenen dökme malzemenin gradasyonuna bağlıdır. Besleyicinin performans araştırması, malzemenin besleyici üzerindeki karmaşık hareketi ve yığındaki parçacık etkileşimi nedeniyle büyük ölçüde deneysel çalışmalara dayanır. Ayrık Elemanlar Yöntemi, çok sayıda parçacığın tanecikli bir akıştaki hareketini hesaplamak için kullanılan ve kaya mekaniğinde etkili bir yöntem olarak kabul edilen bir yöntemdir. Bu çalışmada, yalpalayan bir besleyicinin performansını araştırmak için AEM kullanılmıştır. Besleyici, Rocky DEM yazılımında boşluk, silindir hızı, parçacık şekli ve derecelendirme gibi farklı parametreler için tasarlanmış ve simüle edilmiştir. Parçacık hızları ve yörüngeleri *belirlenerek farklı disk konfigürasyonları için besleyicinin etkinliğini araştırmak üzere parçacık kalma süreleri hesaplanmıştır.*

Anahtar Kelimeler: *Ayrık eleman yöntemi, parçacık şekli, wobbler besleyici*

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INTRODUCTION

Different methods have been developed regarding feeding material in mining industry. Belt, apron, vibratory feeders are such examples. Vibrating feeder is a kind of feeding equipment widely used in metallurgy, coal, electric power, and chemical industries. It is used with other types of equipment together to realize the automatic operation of feeding, batching, quantitative packaging, and other processes (Z.J.Yin vd.,2010). For example, as the feeder vibrations occurred at its resonance frequency, vibration amplitude is highly dependent on a damping factor. On the other hand, the damping factor depends on the mass of the material on the feeder trough, the type of material, and the vibration amplitude (I. F. Goncharevich vd., 1990; T. Yanagida vd., 2001; O. Taniguchi vd., 1963)

Wobbler feeder is another type that is commonly used for removal of dirt and small undesired particles from raw material. Being able to perform two different processes, feeding and sieving, makes wobbler feeder different from others. Some feeders can screen bulk material while conveying materials to next process. Generally, vibrating grizzly feeders, Figure 1. From Meka Global that have grizzle bars are used for both feeding and scalping. Especially, wet and sticky materials may fill the opening between bars and grizzly feeder lack ability of screening unwanted material. To overcome this kind of problems, wobbler feeders are one of the best solutions. Working of a Wobbler feeder is similar to a roller screen. It is used for scalping out fines and feeding only oversize to a crusher. As shown in above figure, elliptical bars of steel are set in alternate vertical and horizontal positions in a Wobbler feeder. The elliptical bars rotate in the same direction, all at the same speed. Spacing between the bars remains constant throughout therotation.

Figure 1. Vibrating feeder and wobbler feeder
Şekil 1. *Titreşimli besleyici ve wobbler besleyici*

Looking at the literature, design workings is investigated using Discrete Element Method (DEM) with The Rocky DEM software. There are increasing reports of simulating of the screening process based on DEM (F. Elskamp vd., 2015; L.L. Zhao vd., 2016; M. Jahani vd., 2015; K.J. Dong vd., 2009; P.W. Cleary vd., 2018; Y.H. Chen vd., 2010). The initial numerical studies of the screening process were conducted with two-dimensional (2D) DEM to investigate the particle motion on the deck (J. Li, C. Webb vd., 2003).Then, a three-dimensional (3D) DEM model for a screening process of particles on a simply vibrated screen deck was developed (P.W. Cleary vd., 2002).

Ashrafizadeh and Ziaei-Rad considered the influence of material shape on its movement and used rectangular blocks instead of mass points to study material

movement using the DEM (H. Ashrafizadeh and S. Ziaei-Rad., 2013) Kong et al. established a sliding and jumping motion model of materials based on Coulomb's law of friction and collision principle, and the model is used to DEM analyze method the changes of material motion under different vibration conditions (X. X. Kong vd., 2015). Considering the studies on the subject are about roller screens which are another type of feeder and design intent is not feeding large sized materials, this work will provide an insight about wobbler feeders screening characteristics. In this study, a wobbler feeder design was investigated using Discrete Element Method (DEM) with The Rocky DEM software. The design variables of the feeder were the spacing between rollers and the rotation speed of the rollers. The effect of material that is fed into the wobbler was also investigated and different particle shape (L/D), the material (limestone and iron ore) and the gradation was simulated. In order to investigate the performance of the feeder, the particle motions were analyzed.

Particle passing percentage through each roller spacing were calculated and the residence time of the particle over the feeder was determined to discuss the performance of the wobbler feeder.Considering the studies on the subject are about roller screens which are another type of feeder and design intent is not

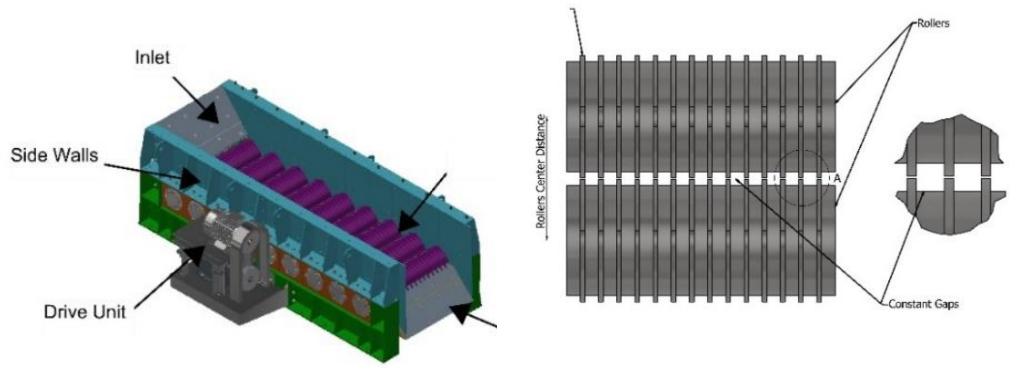


Figure 2. Wobbler feeder disc configuration

Şekil 2. *Wobbler besleyici disk formu* feeding large sized materials, this work will provide an insight about wobbler feeders screening characteristics.

MATERIALS AND METHODS

Wobbler Geometry

The wobbler feeder moves material forward with disc groups rotated by means of chains. All disc groups are rotating synchronously, in the same direction with same speed and two types of wobbler feeders are simulated in which the spacing between rollers are 40x40 mm and 60x60 mm. Overall dimensions of the feeder is 1200 mm in width and 3500 mm in length.

Distances between rollers came from EN standards for the drive chains (DIN 8187:1984). The space between the disc groups always remains the same because of the disc configuration (Figure 2). Hereby, the unwanted materials which are sand, dirt, soil etc. are discharged from those spaces. Besides, the clean particles move forwards along the rotation direction of the disk (Figure 3) and desired materials discharged from the exit. In Table 1, the wobbler feeder's simulation parameters are given in detail.

DEM, Simulation Setup

DEM is an effective numerical method to calculate the mechanical behavior of discrete particles based on Newton's law of motion (H.P. Zhu, et al. 2008, Zhu, Z.Y. Zhou et al. 2007, W.Q. Zhong 2016).

In this work, real size wobbler model is used in simulations. Feeding material chosen as Limestone (G1) and Iron Ore (G2) which are obtained from MEKA customer's material requirements. Their shapes are polyhedron (Figure 4). The size gradation is given inTable 2 and equipment properties are given in Table1. Density, Young's modulus and Poisson's ratio of boundaries are 7850kg/m^3, 210 GPa and 0,3 respectively. Details of all simulation parameters are listed in from Rocky Table 3.

RESULTS AND DISCUSSION

In this part, particle passing percentages, particle movement velocity and particle resident time were examined to obtain optimum parameters for screening efficiency.

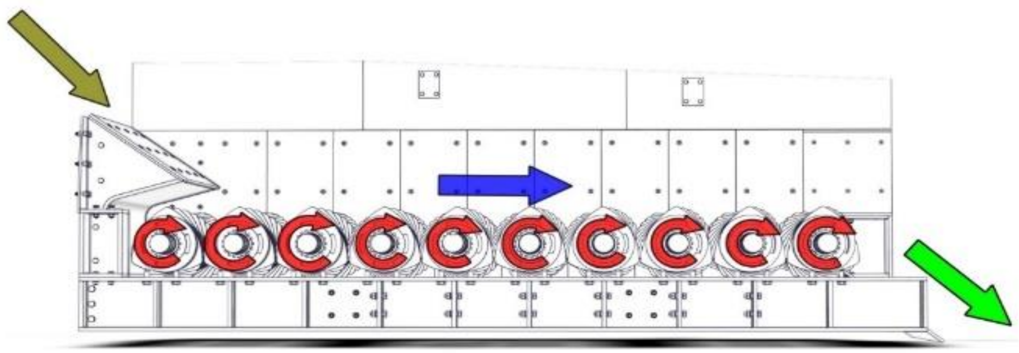


Figure 3. Simulation showing all disk groups running in synchronicity

***Şekil 3.** Eş zamanlı çalışan disk gruplarını gösteren simülasyon*

Table 1. Equipment properties

Tablo 1. *Ekipman özellikleri*

Parameters	Values
Feed rate (t/h)	300
Types of gradation	Limestone (G1), Iron ore (G2)
Number of rollers	12
Spacing (mm)	40x40, 60x60
Roller speed (rpm)	20, 40, 60
Distance between two rollers (mm)	381
Feeder Length (mm)	3500
Feeder Width (mm)	1200
Roller Diameter (mm)	406

Figure.4. Selected feed materials shapes

Şekil 4. *Seçilen besleyici malzemelerin şekilleri*

Particle Passing Percentages

To examine working condition, passing percentages of undersize particles were examined for each spacing. For this reason, 12 cubes were created under each roller as shown in Figure 5. Also, at the exit of the wobbler, cube was created to consider overflow.

In Figure 6. It is observed that, overall passing percentage is increasing with the increase of roller rotation speed. To investigate passing percentages along the wobbler, each section of spacings were examined. Efficiency of all sections under the wobblers are shown In Figure 7.

Passing percentages almost is same for all cases at the beginning of section of the wobbler where nearest to inlet, though there is sharp decrease from 4th section till the 9th section. Also, almost every passing percentage is zero after 9th section which indicate that there is not any undersize material in this section. It also should be noted that generation order of particles changes in every simulation hence smaller particles may be created in the start of the simulation or in the later stages.

Particle passing percentage were examined which is one of the important parameters giving information about efficiency of the wobbler. Although, undersized particles escaped from overflow which is not desirable in application area general screening efficiency is compensating undersized material percent at discharge. As a result, optimum roller speed should be arranged for the optimum operation. Considering these configurations, although 60

Table 2. Size grading of materials

Tablo 2. *Malzemelerin boyut sınıflandırılması*

Particle Size Distribution			
Limestone (G1)		Iron Ore (G2)	
Size (mm)	Cumulative (%)	Size (mm)	Cumulative (%)
609.6	100	1066.8	100
304.8	52	914.4	85
203.2	41	508	70
152.4	34	406.4	61
101.6	27	355.6	56
76.2	22	304.8	52
50.8	17	254	46
38.1	15	203.2	41
25.4	12	152.4	34
19.05	10	101.6	26.7
12.7	8	76.2	22.5
9.53	7	50.8	14.7
6.35	5	38.1	14.9
4.76	4	25.4	12
2.38	3	19.05	9.8
2	0	12.7	8.1
		7.76	4.3
		2.38	3

Table 3. Properties of Limestone (G1), Iron ore (G2) materials

Tablo 3. *Kireçtaşı (G1), Demir cevheri (G2) malzemelerinin özellikleri*

Gradation / Properties of Particles	G1	G2
Bulk Density (mt/m^3)	1.60	2.40
Specific Gravity	2.65	3.40
Coefficient of restitution	0.30	0.30
Coefficient of static friction	0.70	0.70
Coefficient of dynamic friction	0.70	0.70

rpm roller speed has higher efficiency it results in higher percentage of undersize material in overflow thus requires more sections which in turn leads to longer wobbler feeder configuration.

Particle Velocity

Another parameter affecting efficiency of the wobbler is particle velocity (Figure 8.) It should be examined to improve the screening efficiency and to obtain durable machine. To investigate wobbler efficiency, particle velocity was examined at different roller rotation speeds such as 20, 40 and 60 rpm. Totally, 12 conditions were examined, and data were obtained after reaching steady state to get accurate results. Also, size of particles was chosen to be between 80 and 90 mm for all conditions. The reason is that sizes in that range is larger than from both gap sizes. In Figure 8. absolute velocity of gradations at same gap sizes (40x40 mm and 60x60 mm) shown with respect to the roller rotation speed. As shown in Figure 8. For low bulk density particle, G1, absolute velocity at 20 rpm is 0.25 m/s while it is 0.46 m/s for high bulk density particle G2 at the 60 rpm roller speed for the gap size of 40x40mm. On the other hand, velocity change for G1 and G2 are 528% and 236 % respectively. Moreover, gap size for 60x60 mm is shown in Figure 8. For the particle G1, absolute velocity at 20 rpm is 0,18 m/s whereas for G2, it is 0,63 m/s. Also, velocity percentages are 412% and 44% respectively. It is clear that particle velocities are directly proportional to rollers rotation speed. As rollers speed is increasing, particle absolute velocity also increases.

Particle Resident Time and Trajectory

In addition to the particle velocities on the wobbler, particle resident time is another parameter that helps understand particle behavior over the wobbler. When particle resident time is decreasing, there is a possibility of undersized particles escaping to overflow section. On the contrary, increased particle resident time results in undersized particles passing from spacing. Former leads to decrease of performance. To this extent, optimum resident time should be obtained for high performance wobbler. Figure 9. gives detailed information about particle resident times for all cases. The resident times described as particles traveling time between entry and exit of the boundary domain. All values obtained after system reached steady state regime.

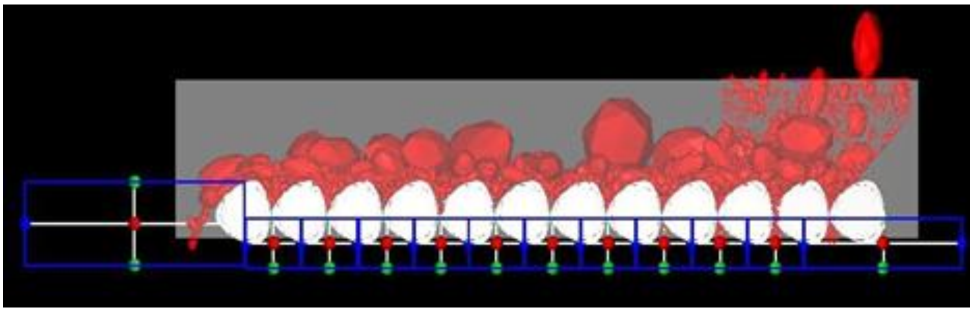


Figure 5. Simulation cube setup for particle passing percentages

Şekil 5. *Parçacık geçiş yüzdeleri için simülasyon küpü kurulumu*

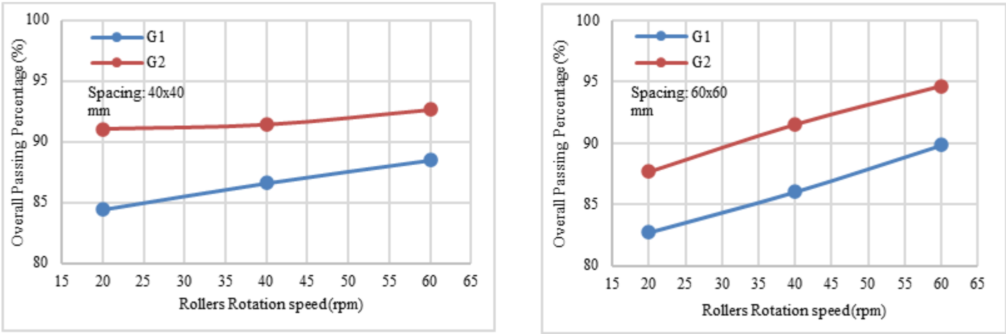


Figure 6. Overall passing percentage

Şekil 6. *Genel geçme yüzdesi*

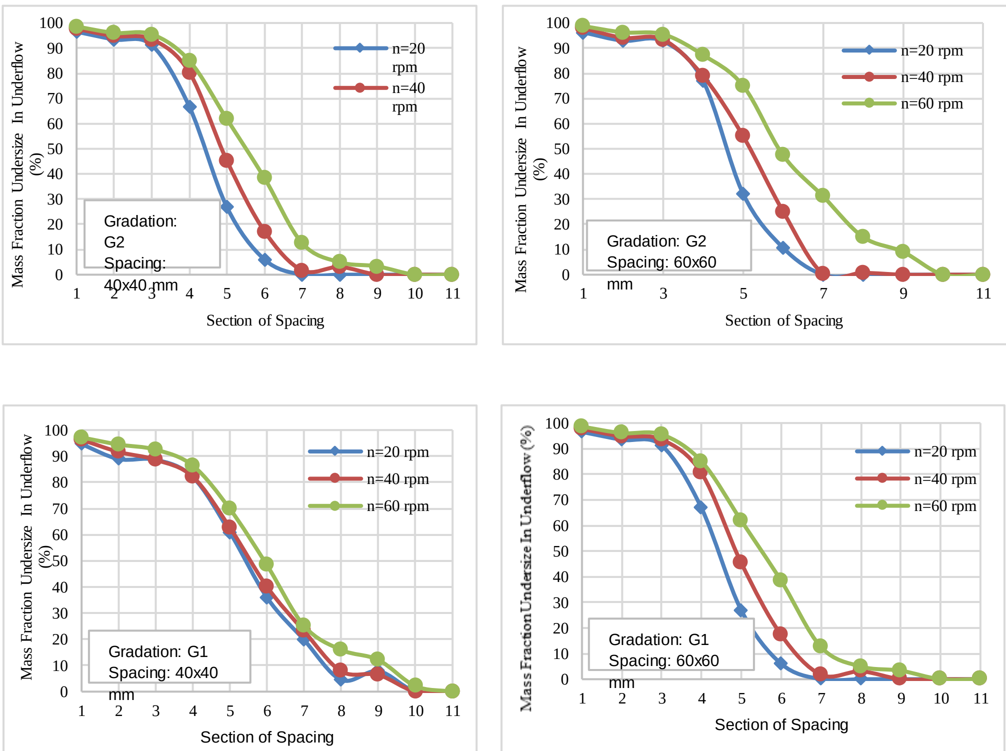


Figure 7. Undersize mass fraction for each spacing

Şekil 7. *Her boşluk için küçük kütle kesri*

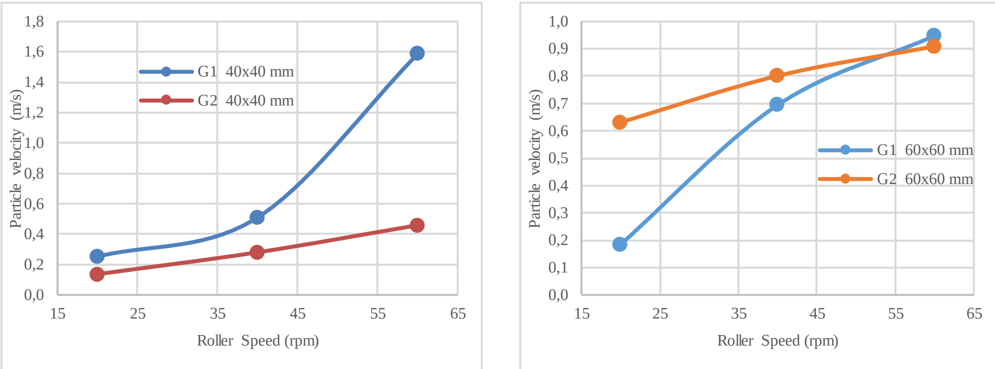


Figure 8. Absolute translational velocity of oversized particles

Şekil 8. *Büyük parçacıkların mutlak öteleme hızı*

Figure 9. shows particle resident time with respect to roller speeds for both low and high bulk density particles. All cases were examined for constant feed rate of 300 t/h. It became obvious that particle bulk density does not have enormous effect on resident time. Nonetheless, resident time is decreasing while roller rotation speed is increasing. For low bulk density particle, resident time is 29.5 sec, 15.45 sec and 11.2 sec in 20 rpm, 40 rpm and 60 rpm respectively for spacing of 40x40 mm. Besides, for high bulk density, resident time is 23.8 sec, 18.9 sec and 11.8 sec in 20 rpm, 40 rpm and 60 rpm respectively for spacing of 40x40 mm (In Figure 9.) Although having higher translational velocity at that time oversized particles moving forward on the Wobbler feeder may experience delayed motion and keep tumbling when stuck in between rollers and result in increased resident time. To understand particle behavior in detail, trajectory of the oversize particle is examined.

Only one particle is selected for all cases and size is chosen between 80-90 mm. In Figure 10, trajectories of the particles are shown for Gradation 1 and spacing 40x40mm. As it can be seen from figures, while rotation speed is smaller, particle is tumbling repeatedly between two rollers. However, in high roller speed, particle moves more quickly as expected. In addition, for undersized and very large particle, trajectories were obtained which is presented in Figure 11. Undersized particle (21.58 mm) directly passed form gaps whereas oversized particle (575.5 mm) moves forwards without any tumbling at 40 rpm, 40x40 mm gap and G1 gradation conditions.

Effect of Different Configurations on Screening Efficiency

The following formula is used to calculate the screening efficiency for condition of 40 rpm,40x40 mm gap and G1.

$$E_u = \frac{Mass_{U_{Underflow}}}{Mass_{U_{Feed}}} \quad (1) \qquad E_O = \frac{Mass_{O_{Overflow}}}{Mass_{O_{Feed}}} \quad (2) \qquad E = E_U * E_O \quad (3)$$

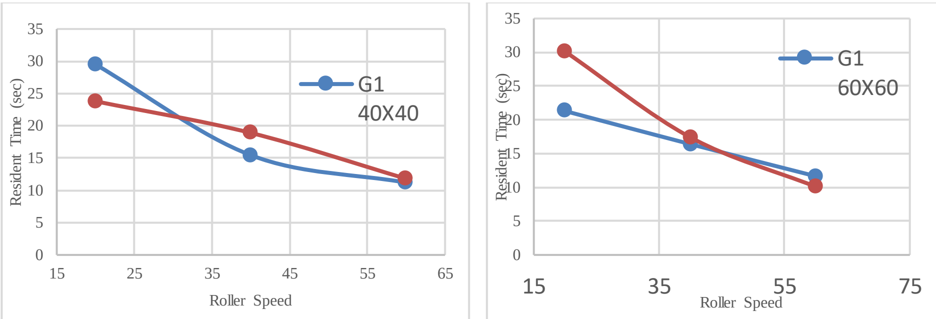


Figure 9. Particle resident time vs. roller speed

Şekil 9. *Parçacık kalma süresi ve silindir hızı*

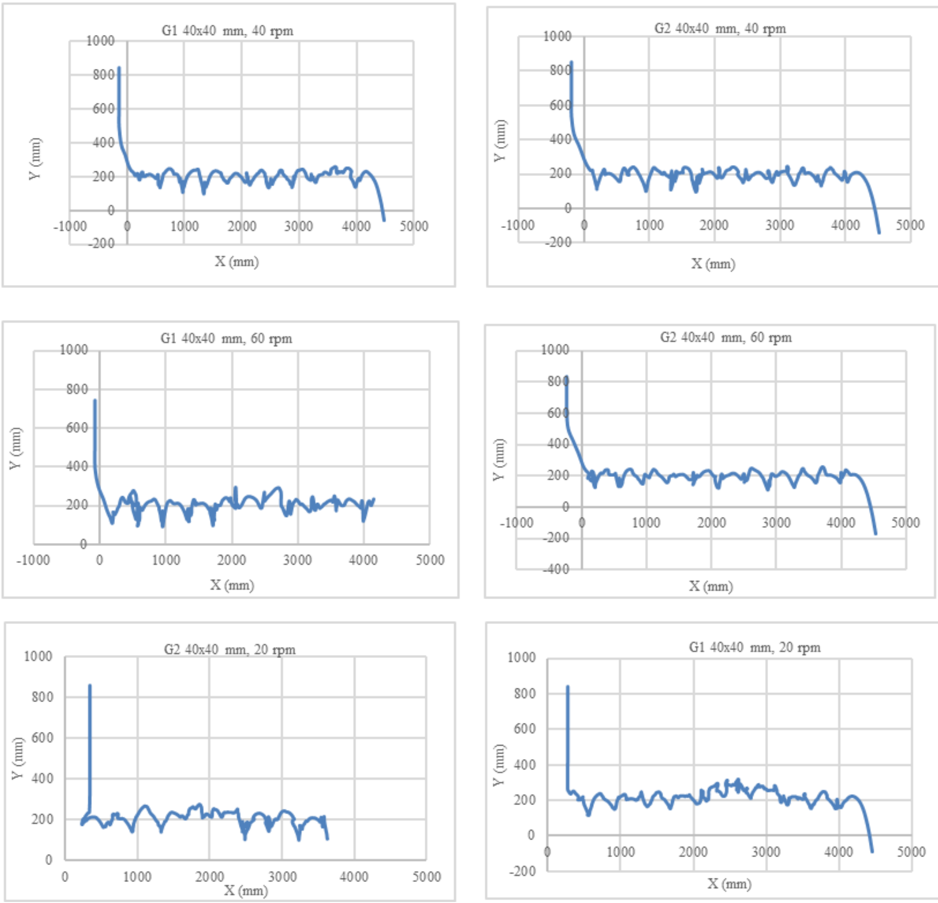


Figure 10. Oversize particle trajectory

Şekil 10. *Büyük boyutlu parçacık yörüngesi*

Efficiency results for corresponding configurations are as follows:

Herringbone configuration:

$$E_u = \frac{1250{,}38\ \mathrm{kg}}{1266{,}85\ \mathrm{kg}} = 0{,}986 \qquad E_O = 1$$

$$E = E_U = 98{,}6\%$$

Straight configuration:

$$E_u = \frac{1238{,}75\ \mathrm{kg}}{1261{,}17\ \mathrm{kg}} = 0{,}982 \qquad E_O = 1$$

$$E = E_U = 98{,}2\%$$

Cross configuration:

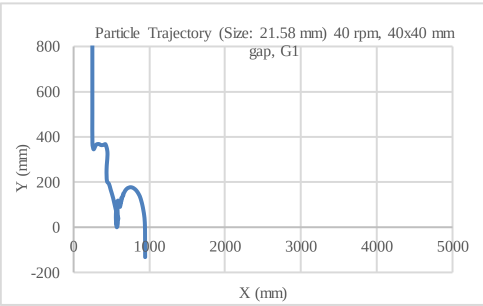
$$E_u = \frac{1196{,}2\ \mathrm{kg}}{1231{,}45\ \mathrm{kg}} = 0{,}971 \qquad E_O = 1$$

$$E = E_U = 97{,}1\%$$

CONCLUSION

In this study, motion of complex raw material for Wobbler Feeder is simulated with Discrete Element Method considering the effects of resident time and particle velocity. Simulations were run for three parameters 20,40 and 60 RPM, which maintains regular feeding of oversize particles and screening of undersize particles from gaps formed by triangular shaped discs.

Based on the results of screening efficiency and particle resident time the optimum roller speed was observed to be 40 RPM for both 40x40 and 60x60 gap. For low bulk density material (G1) resident time is 15.45 seconds whereas for high bulk density material (G2) resident time is 18.9 seconds for 40x40 mm gap. These results indicates that roller rotation speed has an important effect on particle flow characterization and screening efficiency.



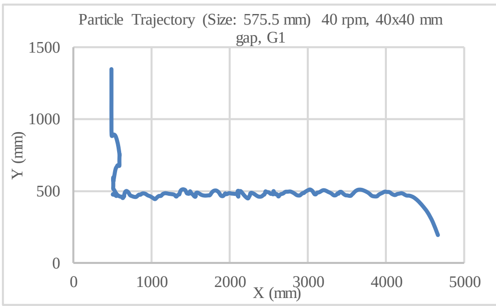


Figure 11. Undersize and oversize particle trajectory

Şekil 11. *Küçük ve büyük boyutlu parçacık yörüngesi*

Although with the increasing rotation speed feeding performance is increasing, it has an adverse effect in terms of particle resident time. For G1 material 40x40 mm and G2 material 40x40mm gap resident times are 13% and 6% higher comparing in 60 RPM compared to 40 RPM. Since decrease in resident time creates a possibility of undersize particle to escape into overflow, and increase of resident time means feeding of oversized particle will slow down, 40 RPM speed is an optimum choice rather than 60 RPM, where resident time is lower and 20 RPM where resident time is higher in described configuration. According to efficiency results herringbone configuration is higher than both straight and cross configurations, while latter two are still have quite adequate efficiency percentages.

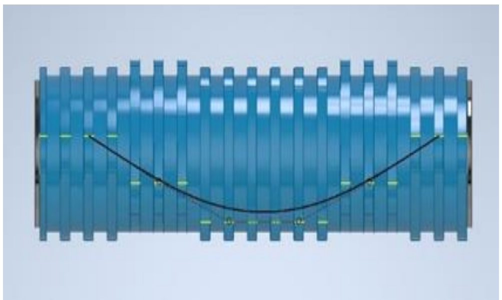


Figure 12. Herringbone configuration

Şekil 12. Balıksırtı form

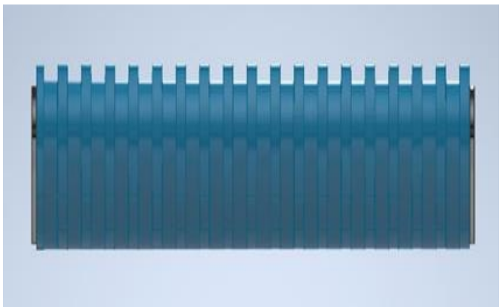


Figure 13. Straight configuration

Şekil 13. *Düz form*

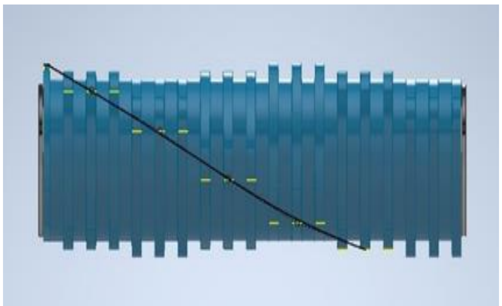


Figure 14. Cross configuration

Şekil 14. *Çapraz form*

For future work study can be done on comparison of simulation results with site tests. Effects of interaction coefficients could also be studied for different types of particles.

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