ISSN: 2578-7365

Research Article

Journal of Chemistry: Education Research and Practice

Experimental Study of Wear in Direct Lines of Pneumatic Conveying of Granular Materials

Mohammad Javidnia MD[1*], Shamsollah Abdollahpour[1]

[1]*Tabriz University, Iran*

*Corresponding author
Mohammad Javidnia MD, Tabriz University, Iran.

Submitted: 13 Jun 2022; **Accepted**: 20 Jun 2022; **Published**: 12 Dec 2022

Citation: *Javidnia, M., Abdollahpour, S. (2022). Experimental Study of Wear in Direct Lines of Pneumatic Conveying of Granular Materials. J Chem Edu Res Prac, 6(2), 434-441.*

Abstract
Pneumatic conveying, is a suitable way to conveying of particles. It costs several dollars to equip pneumatic conveying systems. One of the main problems in the pneumatic conveying system is the wear of the conveying lines. The mechanism of wear experiment designed in the University of Tabriz. In this paper investigates the wear on conveying lines and how to reduce it. The results and analysis of the experiments showed that SS 410 is the best from AA6063, SS 310 and SS 304 alloys. SS 410 has higher abrasion resistance. Higher conveying velocity, it has a significant effect on the wear rate. When, mass flow rate is increasing, abrasion resistance of the conveying line is depending on to time. From the three granular particles, the abrasion behavior of wheat grain and barley are similar.

Keywords: Wear, Pneumatic Conveying, Abrasive, Erosive, Granular, Particle Wear

Introduction
Design of conveying of materials by airflow is a suitable method because in this method combine of theory and experience were used. One of the most important problem in this system, is wear of components in conveying line. The abrasion in this study will be more of a scratch abrasion. Scratch abrasion occurs when a hard, rough surface slides against a softer surface. Scratch wear is defined as a decrease in the mass of the material due to the movement of hard particles on the slip surface. Reducing the wear, will reduce the cost of a new conveying system. By recognizing this complex problem and study, it is possible to achieve the important goal of increasing the interest of manufacturers and industrialists in to use the pneumatic conveying system and also increasing the useful life of pneumatic conveying lines. Despite the great development in the Pneumatic industry and technology in the last century, there are still many problems and complexities in Pneumatic conveying industries, such as:

- The matter of Abrasion is critical when conveying materials such as sand, silica, coal, aluminum, etc.
- An increase in air temperature can cause the powder mixture to become sticky, resulting in clogging and blockage of the pipe.
- Limitations in conveying distance due to requirement high power

Pneumatic or air transfer can be defined as the transfer of dry bulk material through pipelines by positive or negative airflow. It can also be described as the use of air movement to do work. Pneumatic transmission systems are designed to move a certain amount of material over a given distance. Depending on the type of material and the distance, the material can be transported up to 40 tons per hour. By using the pneumatic conveying method, valuable products can be transferred with confidence [1]. Pneumatic conveying system is one of the most suitable methods for transferring toxins and chemical materials. In fact, with proper design, many different materials can be conveyed with a high degree of reliability.

The properties of the transferred solids will greatly affect how the system works. These propertieschange the type of conveying system. However, aqueous, pasty, and brittle materials (in cases where the crushing of the material is important for the final use of the material) should not be transferred pneumatically. The main advantage of Pneumatic transmission is that the material is transferred inside a closed and dry chamber, as a result of which the environmental effects (such as the effect of air pollution, the effect of moisture, etc.) on the material are prevented.

Wear can change due to the inherent properties of solids and the velocity of transfer and wear in bends is more common than anywhere [2]. Currently, low velocity is used for conveying in industrial [3]. Velocity is one of the most important wear factors [4]. To get the most efficiency at the coal industry, we need to know the velocity and size of the Particle being transferred [5].

To date, most experimental studies have been performed on vertical pipes [5]. Pneumatic conveying is done in two ways: in the dilute phase and in the dense phase. The dense phase state itself is divided into the following three states:

- steady state flow regime
- Unsteady state flow regime
- gradient flow regime

Loading ratio($\mu = mS/mg$) in dense and dilute phase [6]:

Table 1: Loading Ratio for Dilute & Dense Phases

Mood Ratio	μ
Dilute phase	0-15
Dense phase	>15

$$\mu = \frac{\dot{m}_s}{\dot{m}_g} \quad (1)$$

Where $\dot{m}_S$ representsthesolid mass flow and $\dot{m}_g$ represents Gas (Air) mass flow and μ represents Loading ratio.

As the flow ratio changes from Dense Phases to dilute phase, the gas velocity, energy consumption, and volume of the solid particles vary like Fig 1 [7].

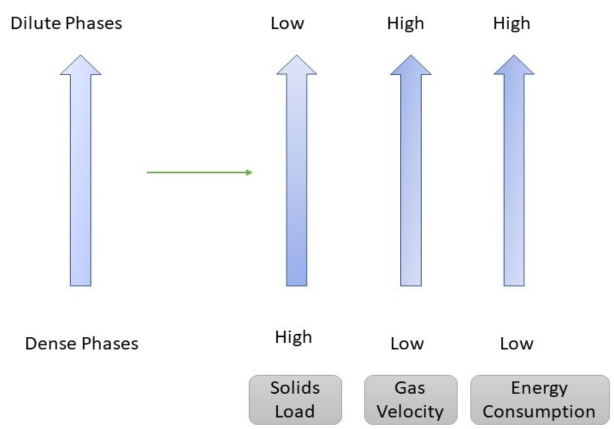

Figure 1: Changes of Gas Velocity, Solids Load And Energy Consumption with Change in Flow Ratio

Features of flow regime in Dilute and Dense Phases [1].

Table 2: Features of Flow Regime in Dilute and Dense Phases

Dense Phases	Dilute Phases
Low Velocity	High Velocity
Less wear	Excessive wear
High pressure (600 to 100 kPa)	Less than 100 kPa
High Cost	lower cost
The ratio of solids to air is high	The ratio of solids to air is low
Need a smaller pipe size	Need larger pipe size

Wear is the most important factor limiting the application of pneumatic conveying [8]. In this paper, the effect of air velocity and particle morphology on Wear of pipe wall is investigated. Frictional force has a significant effect on the wear of Pipes wall [9]. Their hardness and wear rates of typical engineering materials such as Steel 400, Steel 300, AA6063(Aluminium is usually used in the conveying of plastics) and St 37 was further explored [10].

Wear

Deformation Wear: Abrasion is which is caused by sliding. This process occurs by mechanical contact of two surfaces with each other. Deformation due to wear is always associated with cutting. The materials are pulled together, and the deformation of the surfaces occurs as a result of the slipping of the two surfaces under pressure, causing wear [11, 12]. Erosion, which is caused by impact and would be applicable for dilute phase flow.

Cutting Wear: The removal of materials from the surfaces is done by moving particles, they are removed from the surface by forming chips. Erosion wear is of this type [13].

Sometimes both mechanisms work together, but usually one of the mechanisms is more prevalent [12]. In a study conducted at the University of Stuttgart, the wear rate was obtained from the relation (2). A relationship that is a linear*mm*algorithm. Quartz particles were accelerated by a Pneumatic accelerator equivalent to air velocity (35)and the wear *ss*rate was measured [13].

$$I_v = a.v_0^m \quad (2)$$

Where *a* represents the constant number that depending on Target Material, angel of collision, and V0 represents Particle velocity, angle of collision in 90°, value of m is Calculated 1.4 for St 37. Type of Wear in this paper is abrasion.

Materials and Method

Experimental Set Up

In order to conducting experiments, it was necessary that samples were exposed to wear. Thenas shown in Fig. 2 the experimental set-up designed and constructed. This set-up consists of an electric motor (power source), a holding chassis, a rotative tank and samples holder.

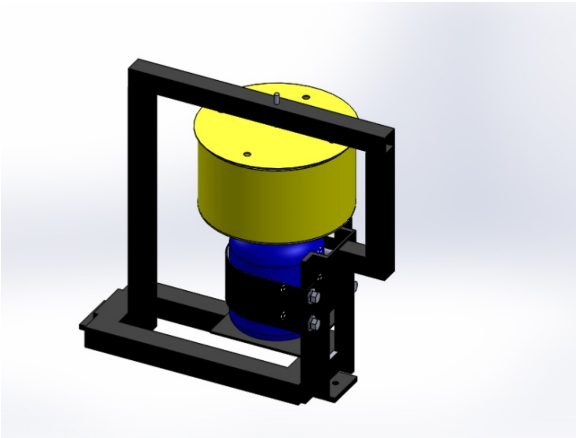

Figure 2: The Experimental Set- Up Sketch

Granular Particles (Materials)

As shown in Fig. 3 Three granular materials were used in experiment: wheat, barley and sand. Due to the fact that Pneumatic Conveying is most used in the transfer of wheat, barley and other particles such as sand and cement, these three types of materials were considered as abrasive particles.

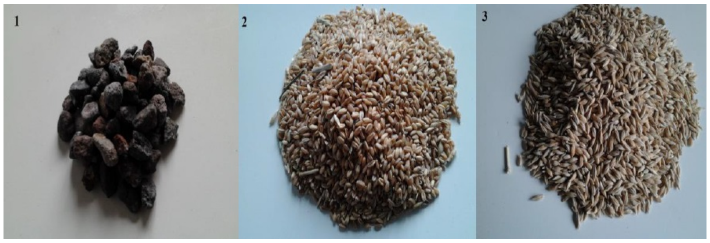

Figure 3: Granular Particles (1. Sand, 2. Wheat, 3. Barley)

Table 3: Properties of Wheat, Barley and Sand Particles

Property	Wheat	Barley	Sand
Density (kg/m^3)	1290	632	1831
Hardness	44(IPS)	50(IPS)	7 (Moh s scale)
Bulk Density (kg/m^3)	771	620	1730
Mean Diameter (mm)	2.77	2.53	7.2
Length (mm)	6.38	8.90	18
Width (mm)	5.8	4.1	12.3
Height (mm)	3.3	2.48	9.8

Table 3 presents the properties (mean diameter, density, hardness, length, width, height and bulk density) of the particles used in this paper.

Test Samples

(a), Steel containing 18% chromium and 8% nickel is called 304 steel.More than 65% of the global consumption of stainless steel includes 300 series steel. This alloy does not have magnetic properties and have high resistant against corrosion, impact and heat [14].

(b), SS 410, is resistant against wear and friction and therefore was evaluated in this study. It is widely used in the construction of pump shafts, machine components, mining machines, valves, screws and etc [14].

(c), ST37 steel is also known as soft steel in the industry. These steels contain small amounts of carbon.And its main application is in construction and building profiles. This alloy is used in the construction of tanks, gas cylinders and oil pipelines.

(d), 6063 Aluminum Alloy is an aluminum alloy, with magnesium and silicon as the alloying elements. It has generally good mechanical properties and is heat treatable and weldable. This alloy has corrosion resistance and is formable. It is typically used in irrigation pipe, railing, furniture, and electrical conduit. Table 4, shows Chemical & Mechanical Properties of Steel 304, Steel 410, St 37 and AA6063.

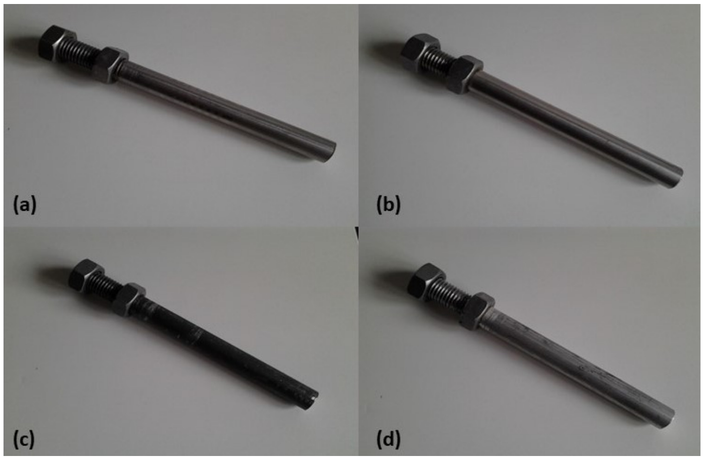

Figure 4: (a) SS 300, (b) SS 400, (c) St 37, (d) AA6063

Table 4: Chemical & Mechanical Properties of SS 304, SS 410, St 37 and AA6063

Name	Composition Hardness	Type	Typical	Composition
SS 304	Fe-19Cr-9.25Ni-2Mn-1Si-0.1N-0.08C 0.045P-0.03S	Austenitic stainless steels	18–25 wt% Cr 8–20 wt% Ni	92 (HRB)
SS 410	Fe-12.5Cr-1Mn-1Si-0.15C-0.75Ni-0.04P-0.03S	Martensitic stainless steels	12–18 wt% Cr < 1.2 wt% C	95 (HRB)
Steel 37	Fe-0.21C-0.065P-0.065S-0.010Ni	Carbon Steel	-	۵۹ (HRB)
AA6063	Al-0.5Mg-0.5Si-0.35Fe	Wrought Aluminum Alloys	-	25 (HB)

Measurement Methods

Wear measurement isdone base on the mass losing of the samples. Loss of mass is a way to measure wear [15]. The particles receive energy and velocity as a result of rotation. Erosion occurs when particles hit with the surfaces of samples. The wear is caused by the Kinetic energy of the particles to the surface of the samples. The reduction in mass is milligramsRange To measure this amount of weight loss, a scale with an accuracy of 0.01 STARTORIUS model was used, which has a load traction capacity of 300 grams.

The appropriate diameter of the 300 mm tank(pipe) was selected. In a study conducted at University of Wollongong, the diameter of the pipes is 4.44, 11.6, 16.5 inch [16]. After construction, the cylinder was connected to a power source and made a circular motion. The material was poured into the cylinder and accelerated and energized by rotational motion.Table 5, shows dimension of tank.

Table 5: Dimension of Tank

Tank	Thickness	Height	Diameter
Bottom plate	2 mm	-	300 mm
Wall Plate	4 mm	200 mm	300 mm

Figure 5, The specimens were installed symmetrically on the cover so that the rotational motion could be easily performed. These specimens made of several components. Figure 6, The test samples are mounted symmetrically on the cover and placed on the rotative tank. The motor spins from below and spins the tank. Due to the rotation of the tank, the particles inside the tank accelerate and hit the test samples severely, and wear occurs due to the impact shock on the test samples.

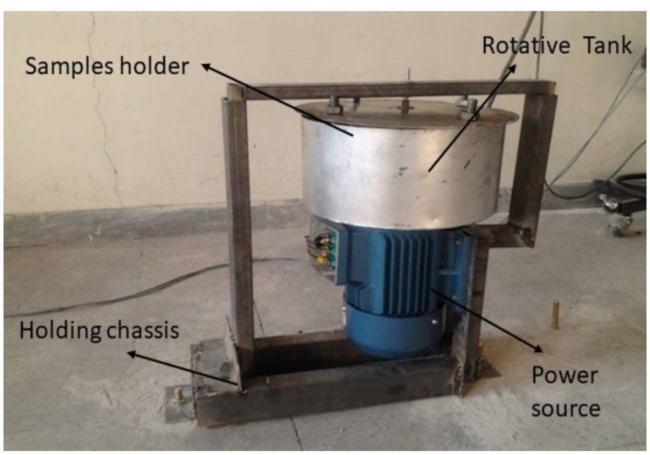

Figure 5: The Experimental Set- Up

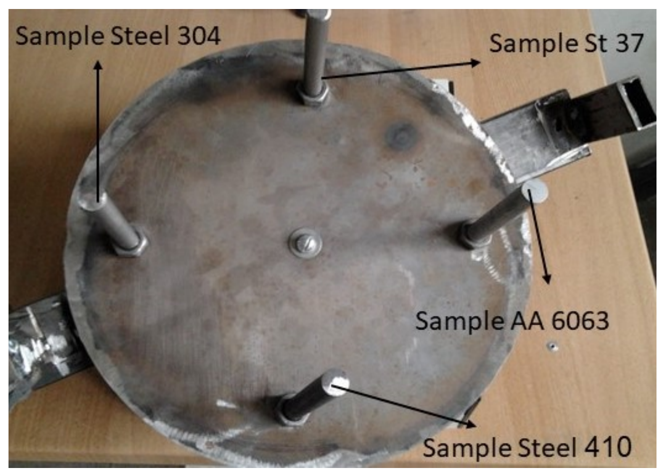

Figure 6: Cover Plate and Test Samples

Table 6, shows Measuring the velocity of particles inside the cylinder and the rotational velocity of the cylinder. The saltation velocity is calculated from Rizk's experimental relationship (3). In the experimental Rizk relation, the geometric diameter must be entered in millimetres [10].

$$\mu = \frac{1}{10^{\alpha}}\left(\frac{V_{salt}}{\sqrt{gD}}\right)^{\beta} \quad (3)$$

Where μ represents the mass Flow Rate and V_{salt} Represents Saltation Velocity and g representsGravitational accelerationand D represents Internal diameter of pipe and α&β is constant factors Obtained from (4) & (5) relationships.

$$\alpha=1.1d_p+2.5 \quad (4)$$

$$\beta=1.44d_p+1.96 \quad (5)$$

Where d_p(mm)represents Geometric diameter of particles.

Velocity of particles is obtained from equation (6) and rotation velocity it was found from equation (8)

$$Vs=Va-Vsalt \quad (6)$$

$$Va=\alpha a.Vsalt \quad (7)$$

$$\omega=\frac{v_s}{r} \quad (8)$$

Where V_a represents velocity of air, r represents radios of tank and ω represents rotational velocity of tank. Table 6 shows range of conveying velocity of 4 granular particles.

Table 6: Velocity of Material Conveying

Product	Carrying Velocities (m/s)
Sand	30 - 43
Wheat, Corn	25-36
Barley	20-31
Beans	31

In addition, the effect of surface roughness on the wear rate was investigated using experimental equations and Moody diagrams.

Results and Discussion

ANOVA

After design and construction of system, the initial tests were performed and after ensuring the accuracy of the device, the main experiments were conducted in the form of a factorial design and the initial data were recorded and analyzed. ANOVA of data showed that there was a significant difference between the types of granular particles, the different tubes, and the velocity of rotation, in terms of the amount of wear at the 1% probability level. mutual interaction effects of (material of samples on granular particle types, material samples on velocity, granular particle types on velocity) and Three-way interactioneffect(material of samples on granular particles on velocity) of wear rate, were significant at the probabilitylevel, 1% Table 7.

Table 7:Variation Analysis of the Effect of Factors on the Amount of Wear

Mean Squares		
Source of Variation	**Degrees of Freedom**	**Valueof Wear(ΔW) in gram**
Particle(A)	2	0.178**
Samples of Test(B)	3	0.164**
Velocity(C)	2	0.278**
A×B	6	0.78**
A×C	4	0.11**
B×C	6	0.105**
A×B×C	12	0.006**
Repetition	2	2
Error	36	0.001
CV(%)	-	11.81 %

**Significant difference at 1% probability level, in each column

Comparison of Means

Comparison of Mean Levels of Granular Particles

Comparing the mean effect of different types of granular particles on the wear rate showed that the highest amount of wear was achieved, when sand is used as granular particle test. this was significantly higher than in wheat and barley. Although the wear rate in the barely as a granular particle was higher than that of wheat, this significant value was not obtained Figure 7.

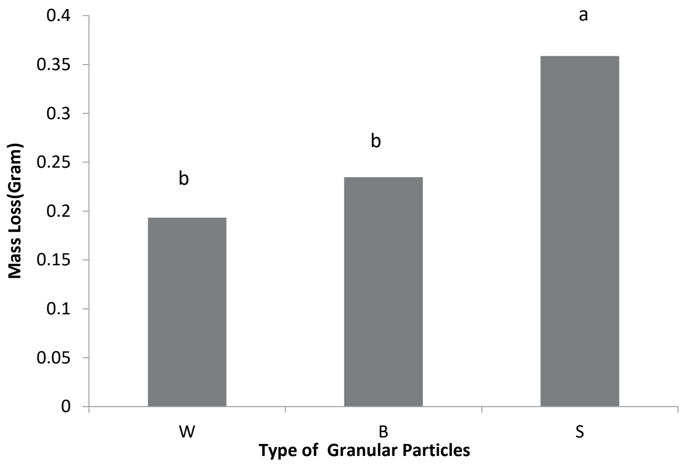

Figure 7: Comparison of mean levels of granular particles. Sand (S), Barley(B), Wheat(W)

Increasing of particle due increasing of momentum and Kinetic energyand effective area Raises of wear rate. Corner particles create higher erosion rates than their spherical particles in metals. Increasing the hardness of abrasive particles also directly affects the rate of wear. The amount of wear depends on the length of the pipe closure, the characteristics of the material being transferred, such as the shape, size, type of material and the area of contact with the wall [8].

Comparison of Mean Levels of Material of Samples

Figure 8.showsfrom 4 samples, high wear rate, was observed in AA6063 had a significant difference .There was no significant difference between other types of steel samples in terms of wear rate.

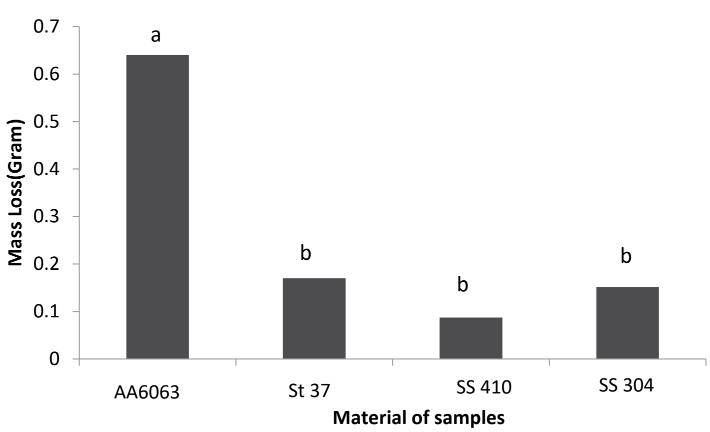

Figure 8: Comparison of mean levels of Material of samples. AA6063, Steel 37, SS 410, SS 304

Comparison of Mean Levels of Conveying Velocity

Figure 9. shows increase wear rate with increase conveying velocity. First, the experiments were performed at 3 Velocity *mm* of 500, 1200 and 2300 rpm, and then the case velocity of 7.8, 18.9 and 36 *(m/s)* were obtained from Equation (8). The *ss* velocity of the particles when impact with the target surface has the greatest effect on the wear rate. That the damage to the transfer material increases with increasing conveying velocity [17]. In experiment on the exchangers, fly ash feed *mm*with velocities range (95.2 to 197*m/s*) and was observed the rate of wear is change as an exponential function [18].

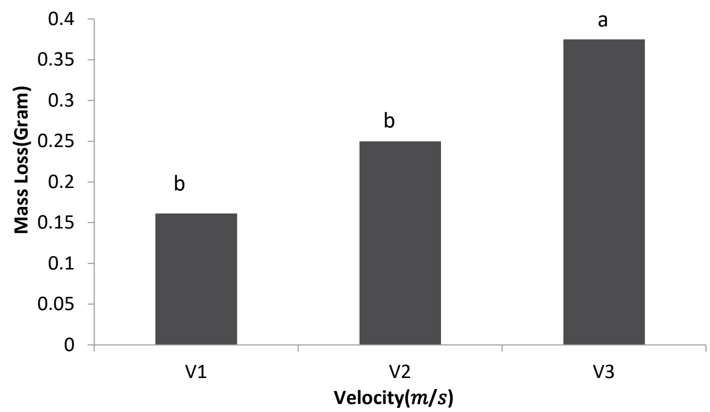

Figure 9: Comparison of Mean Levels of Conveying Velocity (V_1=7.8*m/s*, V_2=18.9*m/s*, V_3=36*m/s*)

Comparison of Mean Treatment Compositions

Comparison of the Mean Treatment Composition Conveying Velocity and Granular Particle

Figure 10. shows as the Conveying velocity increases and hardness of granular particle increases, wear rate increases. In other words, increasing the size and weight of the particles, changing the morphology of the particles and also *mm* increasing the wear rate. The maximum amount of wear at a transfer rate of 36m/s for sand and value of wear 0.6 Was obtained.

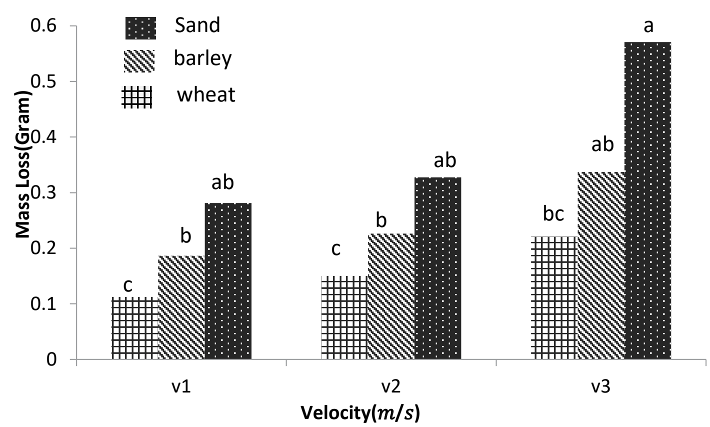

Figure 10: Comparison of the Mean Treatment Composition Conveying Velocity and Granular Particle (V_1=7.8*m/s*, V_2=18.9*m/s,* V_3=36*m/s*)

Comparison of the Mean Treatment Composition Conveying Velocity and Material of Samples

Figure 11. shows Comparison of the mean treatment composition for 4 type of materials with velocity 7.8, 18.9 and 36*m/s*. Result shows maximum rate of wear occurwhen velocity of conveying was 36*m/s*, and AA6063, was consideredas material of samples. Value of wear rate obtained 0.96g It was significantly more than

others. Minimum rate of wear obtained for St 410 with velocity of 7.8*m/s*. thus, result shows St 410 is the most appropriate material for conveying of granular particles and AA6063, is the worst. On the other hand, change in velocity effective on wear rate.

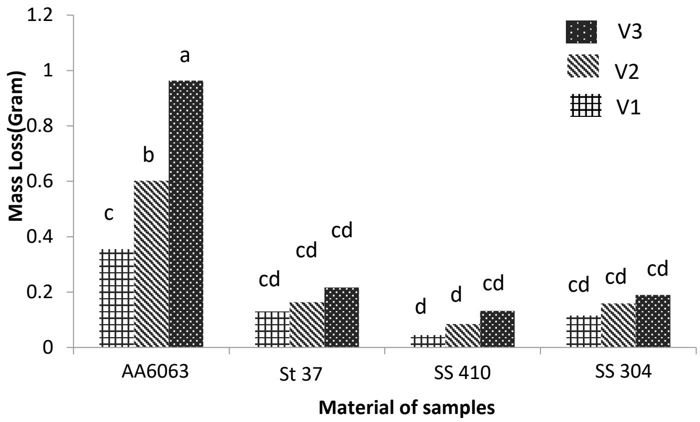

Figure 11: Comparison of the mean treatment composition Conveying Velocity and Material of samples (V_1=7.8*m/s*, V_2=18.9*m/s*, V_3=36*m/s*)

Comparison of the Mean Treatment Composition Granular Particle and Material of Samples

Figure 12. shows Comparison of the mean treatment composition for type of materials and granular particles. Maximum rate of wear occurs when sand considered as granular particle, and Al was as e material of samples. Value of wear rate was obtained 0.98g It was significantly more than other composition. This may be due to the relativelow hardness of aluminium compared to other materials. Minimum rate of wear obtained for St 410 In the presence of wheat as a granular particle.Therefore, it can be concluded that for conveying of all 3 materials(sand,wheat,barley), St 410 is the best material.

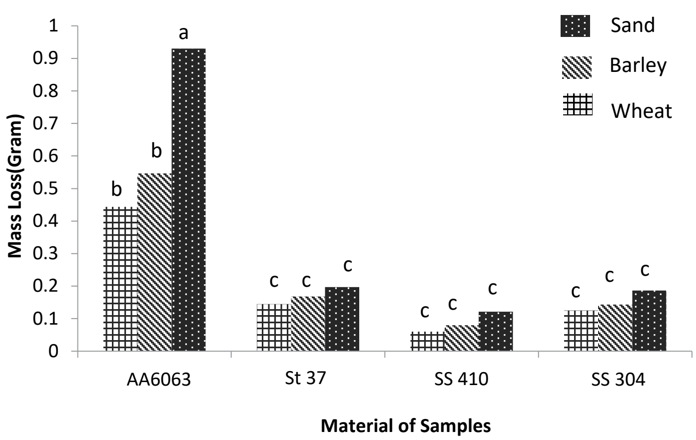

Figure 12: Comparison of the Mean Treatment Composition Granular Particle and Material of Samples

Relations Between the Studied Factors and the Rate of Wear

Relation (9) shows Relations between granular particles, material of samples, conveying velocity and rate of wear analyzed with regression model. Regression analyzed showed there is positive significantly relation between type of granular particles and conveying velocity with rate of wear. ANOVA showed increase of hardness have positive effect on wear rate. In addition,there was relation between conveying velocity and wear rate it means higher velocity produces more wear. relation between material of samples and wear rate was negative, it means increasing hardness than AA6063 to Steel, rate of wear decreased. Relation (9) shows Regression analyze of factors.

$$\Delta M= 0.31+0.08(A)-0.17(B)+0.11(C) \quad (9)$$

Where (A) represent Type of granular particles, (B) represent Material of sample (C) represent conveying velocity and (ΔM) represent Wear rate.

Relations Between the Particle Size and Hardness with Rate of Wear

Figure 12. shows Relation between wear(Mass Loss) and hardness When the surface hardness of the material is high, more energy is needed to scrape it.

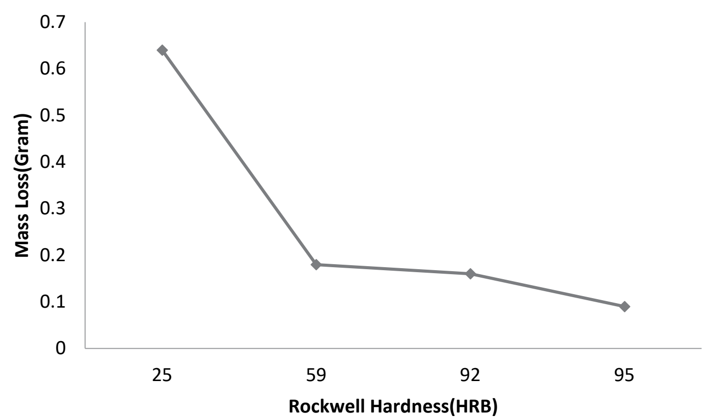

Figure 13: Relation Between Wear and Hardness

Figure 13. shows Relation between wear(Weight Loss) and Particle size. As the increasing of particle size, the amount of wear increases. In addition, the morphology of the particle is also effective in abrasion. Spherical particles have less wear than sharp particles.

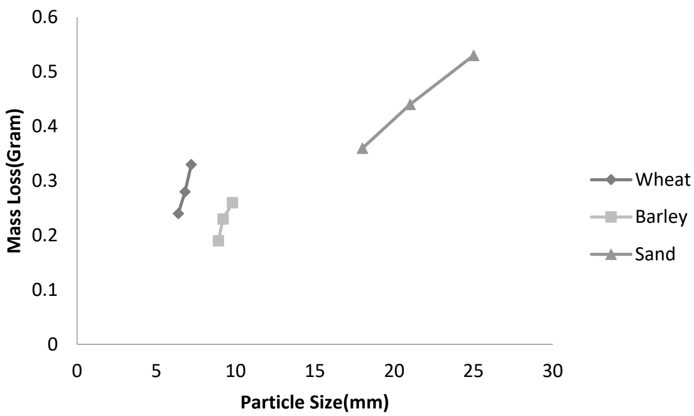

Figure 14: Relation Between Wear and Particle Size

Conclusion

The results showed that for pneumaticconveying, the best material that is resistant to wear is St 410 which is more resistant than other types of pipes.Increasing the velocity of material transfer inside the pipe, leads increases the wear rate of direct pipes. In addition, with increasing hardness of the granular particles, the amount of wear of the pipes increases significantly. The relationship of between wear and hardness is linear. Increase of hardness leads to reduce of wear. In addition to size of abrasive particles is matter on wear rate. The mechanical behavior of barley and wheat is similar to each other, so you can consider one of them in other research. It is recommended to design of silos and Processing plantsof barley or wheat, mechanical properties of sand should be considered.

References

1. S, Hall. (2012). Fluid Flow.
2. Klinzing, G. E., Rizk, F., Marcus, R., & Leung, L. S. (2011). Pneumatic conveying of solids: a theoretical and practical approach (Vol. 8). Springer Science & Business Media.
3. Tomita, Y., Funatsu, K., & Harada, S. (2001). Granular jump in low velocity pneumatic conveying of solid particles in a horizontal pipeline. In Handbook of Powder Technology (Vol. 10, pp. 353-359). Elsevier Science BV.
4. Mills, D., Jones, M. G., & Agarwal, V. K. (2004). Handbook of pneumatic conveying engineering. Crc Press.
5. Wu, X. C., Wu, Y. C., Zhang, C. C., Li, G. N., Huang, Q. X., Chen, L. H., ... & Cen, K. F. (2013). Fundamental research on the size and velocity measurements of coal powder by trajectory imaging. Journal of Zhejiang University SCIENCE A, 14(5), 377-382.
6. Mathew, J., Ma, L., Tan, A., Weijnen, M., & Lee, J. (2011, October). Engineering asset management and infrastructure sustainability. In Proceedings of the 5th World Congress on Engineering Asset Management (WCEAM 2010), Cincinnati, OH, USA (pp. 3-5).
7. E. J. Hooker. (1977). Pneumatic Conveying.Eng Mater Des, 21(7), 44-47.
8. GKlinzing, G. E. (2016). Novel, unusual and new videos and pictures in pneumatic conveying. Powder Technology, 296, 53-58.
9. Pahk, J. B., &Klinzing, G. E. (2012). Frictional force measurement between a single plug and the pipe wall in dense phase pneumatic conveying. Powder technology, 222, 58-64.
10. K. Jacob. Introduction to Pneumatic Conveying of Solids Goals for this webinar.
11. Bitter, J. G. A. (1963). A study of erosion phenomena part I. wear, 6(1), 5-21.
12. Cenna, A. A., Page, N. W., Williams, K. C., & Jones, M. G. (2008). Wear mechanisms in dense phase pneumatic conveying of alumina. Wear, 264(11-12), 905-913.
13. Kleis, I., &Kulu, P. (2007). Solid particle erosion: occurrence, prediction and control. Springer Science & Business Media.
14. Tripp, E. H. (1942). Materials handbook. Nature, 150(3798), 195-196.
15. Gobind, GN., Parshad, J. (2015). Techniques of measuring wear for bulk materials and advanced surface coatings. IOSR J Mech CivEng (IOSR-JMCE), 12(2), 101–106.
16. Pan, R. (1992). Improving scale-up procedures for the design of pneumatic conveying systems.
17. Lalit, R. V., & Chung, M. T. (1993). Pneumatic conveying of grains. Louisiana state University. Journal for Hawaiian and Pacific Agriculture, 4, 1-13.
18. Habib, M. A., Badr, H. M., Said, S. A. M., Ben-Mansour, R., & Al-Anizi, S. S. (2006). Solid-particle erosion in the tube end of the tube sheet of a shell-and-tube heat exchanger. International journal for numerical methods in fluids, 50(8), 885-909