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Dynamic of the Elbow's Wearing Process in Pneumatic Sand Conveying Facilities

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Abstract

The paper presents the experimental research of the erosion phenomena in pneumatic sand conveying. The sand conveying process causes intense wear in the system components mainly in the areas of flow direction change, both in the case of helical and pneumatic conveyer.

Dynamic of wear process was determined by measuring the components wall thickness in the areas of maximum wear.

Measurements indicated the wall thickness variation during a working period of seven months. Practical results are in good agreement with theoretical support.

Introduction

Technological installations providing mixtures based on sand perform their conveyance either mechanically, by using a conveyer worm, as in the case of cementing trucks, or pneumatically. Pneumatic conveying is an easy and convenient way to convey powdered or grained materials and it represents a modern solution due to the following advantages:

- long distances transfer of significant quantities of sand grain-size fractions;
- easy compensation of the relatively big differences in height, between the components of pneumatic conveying;
- short time of technological transfer operations;
- significant run-over sand flow independent of the product grain size;
- easy maintenance with minimum expenses.

Studies have shown that the sand conveying process causes intense wear in the system components mainly in areas of changes in flow direction, both the in case of helical and pneumatic conveyer.

The components of a pneumatic conveying facility subject to wear are mainly pipes and elbows also called bends. According to the conveying distances, elbows that are of 30º or 90º type are normally used, as well as special profile bends.

This paper presents the methodology and main results of a research on the wear rate of elbows as components of sand pneumatic conveying equipment, according to its constructive and functional parameters.

Sand Pneumatic Conveying Process

Parameters influencing pneumatic conveying

If a material is conveyed in suspension in air, it is referred to as dilute phase conveying. In dilute phase transport (sand/air), an air velocity about 13 to 16 m/s must be maintained in order to keep solid material in suspension.

The conveying capability of the system depends on the properties of the conveyed material and also on the system geometry.

Properties of the conveyed material that can influence the conveying capability and the potential flow rate that can be achieved include the following: mean particle size, particle size distribution, particle shape, particle and bulk densities, air retention and permeability [1].

Parameters influencing pneumatic conveying are the following:

- *Particle velocity*: Particles also move at a velocity lower than the mixture velocity due to the friction forces. The difference between these velocities is called the slip factor. For most course or hard solids, the slip factor is around 0.80. According to some authors [1], particle velocity in pipes is about 80% of the air velocity.
- *Pressure drop*: Because of the change of direction, of the impact of particles with the elbow wall, and of the turbulence, there is a pressure drop across the elbow and pipe [2, 3]. In these conditions, to exit the elbow the re-acceleration of particles up to the velocity of transport is necessary.
- *Bend geometry and the particle impact angle*: For erosion applications it is assessed that the angle of attack, particle shape and size, material type as well as the particle velocity will influence the particle exit angle and velocity [4]. At a curved elbow [5], in function of *D/d* ratio, the particles will impact against the elbow wall at an angle of about 20º or more. The impact area is exposed to erosion and can be expected to fail quickly. Fig.1 indicates the influence of the bend geometry on the particle impact angle, α .

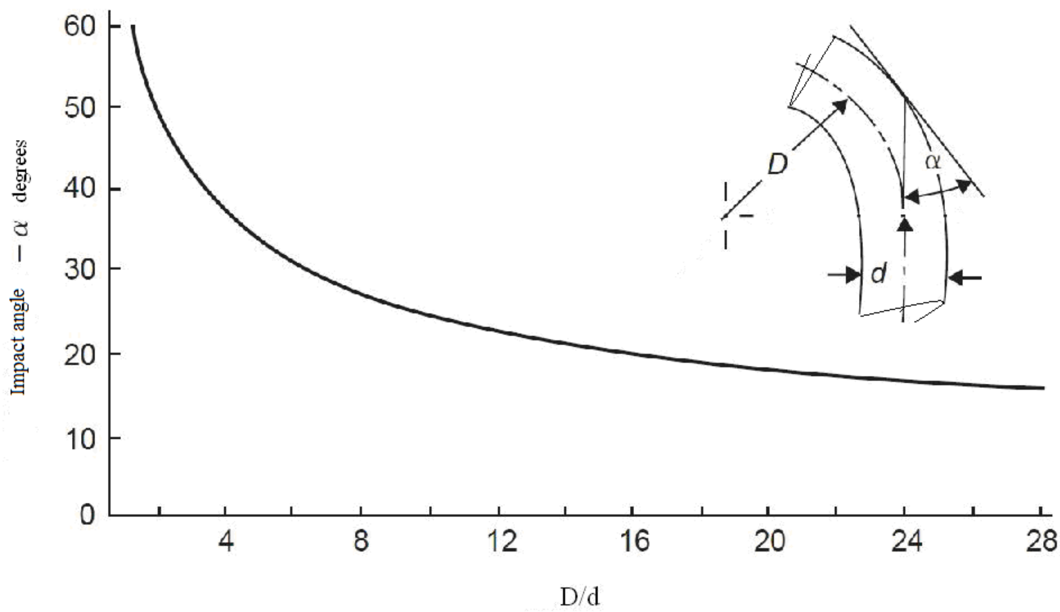

Fig. 1. Influence of the bend geometry on the particle impact angle

In case of a bend with special geometry, the material movement is presented in Fig. 2. [6]

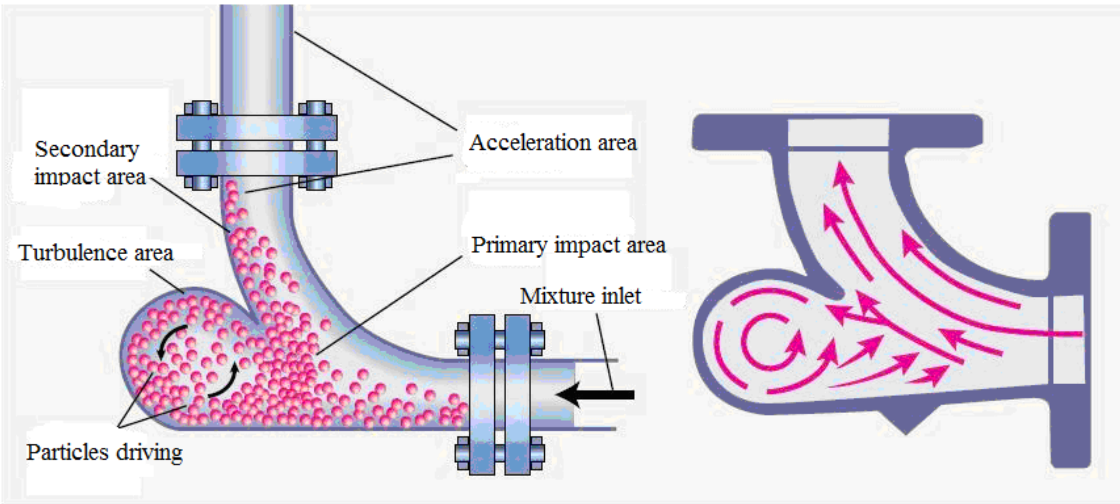

Fig. 2. Influence of the bend geometry on the particle impact angle

Empirical method to predict erosive wear caused by sand conveying

During the pneumatic conveying of solids by the pipelines, solid particles are of higher density than the air stream and therefore cannot follow gas streamlines when rapid changes in direction occur. Under such conditions, solid particles collide with the wall and the resulting impact and momentum loss causes erosion of the wall. While turbulent fluctuations can cause particle to impact the wall, the erosion losses are minor in parallel flow along a pipe, compared to those obtained at a 90 degrees diverter [7].

As a prime approach, erosion limits have been calculated using API RP 14E equation, [8]:

$$V_e = \frac{c}{\sqrt{\rho_f}} \tag{1}$$

where: V_e is the maximum air velocity (m/s); ρ_f – the density of the mixture (kg/m^3); c – empirical coefficient proposed by API RP 14E, equal to 100 for continuous operation and to 125 for intermittent operation.

This equation is valid for flow in horizontal pipe.

In time, many researches and investigators have verified the accuracy of equation (1) and extended the applicability of RP 14E to the elbows and tees. They have taken into account other factors too, like particles size and shapes, impact angle, component geometries and fluid density.

Huser and Kvernvold [9] proposed an empirical equation to describe the wear rate variation with impact angle:

$$E(\alpha) = C \times V^{n(\alpha)} \tag{2}$$

where E is the erosion rate (mm/an); α – the impact angle (degrees); C – constant depending on the material and erosion conditions; V – air velocity (m/s); n – velocity exponent depending on the material and the impact angle.

Salama and Venkatesh have proposed a new model for the prediction of wear rate in elbows by using simple empirical correlations with the fluid velocity [7, 9].

This model takes into account the sand density of 2650 kg/m^3 and was formulated as follows:

$$ER = 37.585\,\frac{WV^2}{PD^2} \tag{3}$$

where ER is the erosion rate (mm/year); W – sand rate (kg/s); V – air velocity (m/s); D – pipe diameter (m); P – steel hardness parameter [10].

The equation (3) of the Salama and Venkatesh model neglects the sand particle size and shape, the sand hardness and it is inapplicable to two-phase flow.

Salama incorporated the effect of two-phase mixture density and particle size into equation (3) and proposed the following equation:

$$ER = 435\,\frac{WV^2 d}{S_k D^2 \rho_m} \tag{4}$$

where ER is the erosion rate (mm /year); W – sand rate (kg/s); V – air velocity (m/s); D – pipe diameter (m); d – particle diameter (m); S_K – a geometric factor equal to 5.5 for elbows [11]; ρ_m – mixture density (kg/m^3).

Based on the Computational Fluid Dynamics simulation method, using numerical method and a particle equation of motion (Euler, Lagrange), the sand particle velocity and angle of impingement (impact angle) are predicted.

CFD simulation of sand erosion is generally performed in four steps. In the first step, the model is built and divided into sub domains using a grid generation technique. In the second step, the fluid velocity values are predicted along the flow direction by solving a flow model and a turbulence model. In the third step, sand particles velocity and angle of impingement are predicted using a particle equation of motion (Eulerian or Lagrangian). And finally, the data of particle velocity and impingement angle are introduced to an erosion prediction model to predict the erosion rate.

The calculated particle velocities and angles of impingement (impact angle) are substituted into the following equation to calculate the erosion rate at every node in the assigned wall [7].

$$ER = \sum_{p=1}^{N} \frac{m_p C(d_p) f(\alpha) v^{b(v)}}{A_{face}} \tag{5}$$

where m_p is the particle mass (kg); d_p – particle diameter (m); α – impact angle; v – particle velocity (m/s); A_{face} – erosion spot area (m^2); C, f, b vary according to particle size, impact angle and particle velocity.

In this simulation, a function has been assigned to the impact angle , taking into account that the particle trajectory and implicitly the velocity change after the wall impact.[7].

Angle function defined by the model is according the following table [7].

Table 1. Angle function

Impact angle	Angle function f(α)
0	0
20	0.8
30	1
45	0.5
90	0.8

The variation of the erosion rate with air velocity is presented in Figure 3 [10].

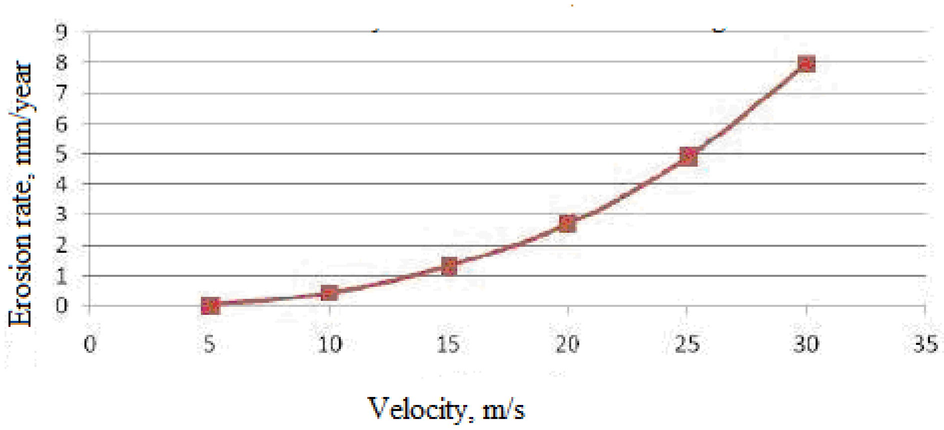

Fig. 3. Variation of the erosion rate versus air velocity

Researches regarding elbows wearing in sand pneumatic conveying facilities

Researches have been carried out for a pneumatic conveying facility having the following characteristics:

- Conveyed material: sand with 1.3 mm grain size;
- Mixture density: 1.3 t/m^3;
- Weight rate: 18 000 kg/h;
- Necessary carrying air: 12 Nm^3/min;
- p_{air}: 2 bar.

The sketch of the conveying system and measurement areas are shown in Figure 4.

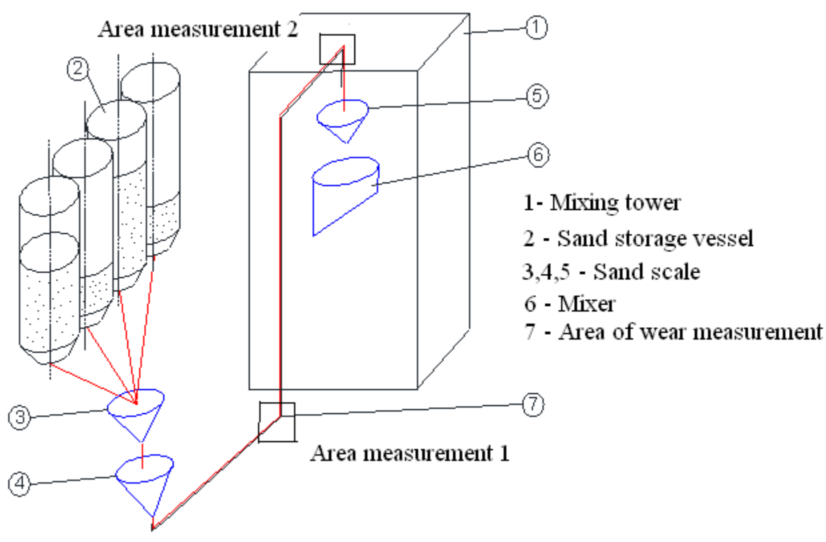

Fig. 4. Sketch of the conveying system

The natural sand transported has the chemical composition shown in Table2.

In the plant, sand to be transported undergoes a process of separation, according to grain dimension. Granulations used are presented in Table 3.

Table 4 presents the materials from which the system components are made.

Table 2. Chemical composition of the conveying sand

Sand	Symbol	Levigable component content %	SiO_2 %	Al2O3 %	Na_2O %	K_2O %	Iron oxides %
quartz sand	1C	less than 2	84.5	8.3	2.1	1.6	1.5

Table 3. Sand granulation

Residue on 1 mm sieve	0.4
Residue on 800 µm sieve	0.6
Residue on 630 µm sieve	2.0
Residue on 500 µm sieve	5.4
Residue on 400 µm sieve	10.6
Residue on 100 µm sieve	78.8

Table 4. Type of steel used for pneumatic conveying pipes

Material	Chemical composition						Mechanical characteristics				
	C max	Si max	Mn max	P max	S max	Al max	R_m N/mm^2	$R_{p0.2}$ N/mm^2 min.	A_5 % min	KV 0°C J	KV -10°C J
P 235 TR 2 SR EN 10216-1:2003	0.16	0.35	1.2	0.025	0.02	0.02	360-500	235	25	40	28
P 235 GH SR EN 10216-2:2003	0.16	0.35	1.2	0.025	0.02	0.02	360-500	235	25	40	28
P 355 N SR EN 10216-3:2003	0.2	0.5	0.9-1.7	0.025	0.02	0.02	490-650	355	22	40	55

Elbows are made from basalt coated steel as well as from cast iron. The used cast iron is of flaked graphite type, with main characteristic presented in Table 5.

Table 5. Type of material used for elbows

Material brand	Chemical composition						Mechanical characteristics					
Si max	C max	Si max	Mn max	P max	S max	Al max	R_m N/mm^2	$R_{p0.2}$ N/mm^2 min.	A_5 % min	KV 0°C J	KV -10°C J	$R_{p0.2}$ warm N/mm^2
GG 25 EN 1561: GJL-250	2.9-3.3	1.5-2.0	0.7-1.2	0.3	0.12	-	250	-	-	-	-	-

The conveying system has worked, after he was put into operation, for seven months in the following conditions: a production of 6100 t was achieved working on one shift. According to the main products prescriptions, the obtained production contained 65% sand of 0-0.56mm grain size.

During this period and the conditions listed above, the elbow was affected by wear up to the wall destruction.

The elbow geometry is presented in Figure 5. The version of the elbow used for the conveying system is basalt coated steel body.

Fig. 5. Elbow geometry

It can be noticed that in the monthly predictive maintenance program, which runs for 24 hours, in the last working day of each month, there are provided dismounting activities of some components, in order to establish and repair certain observed defects. Of high importance are elbows inspections, which are known from practice that registers maximum wear. During these inspections it was found that after four months the basalt coating was eroded in some areas. Typical aspect of the weared surface is presented in Figure 6.

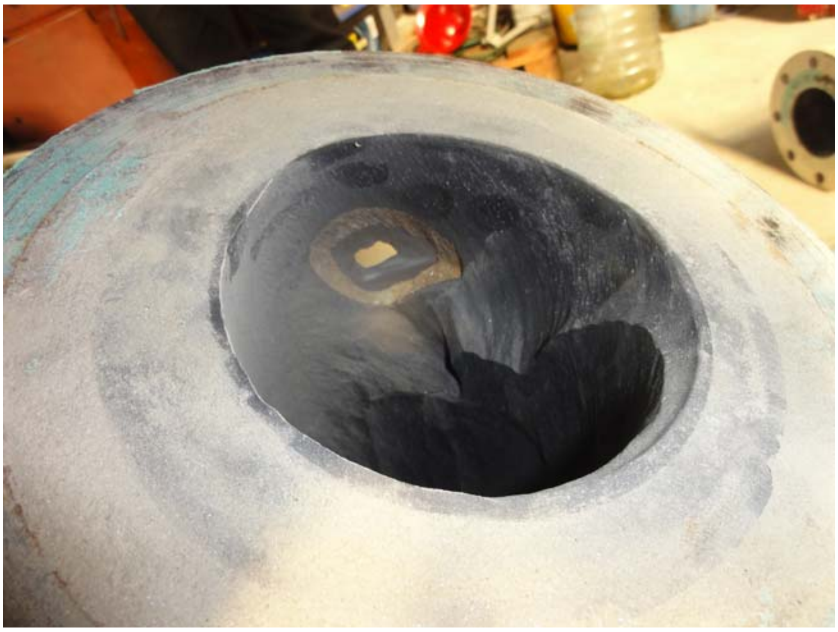

Fig. 6. Registered wear

Registered high wear velocity, in the analyzed period, has led to a removal of the elbow leading to periods of shutdown of the plant.

The dynamic of the wear process was determined by measuring the steel elbow wall thickness in the areas where wear occurrence was noticed and it was analyzed in relation to working time.

Measurements were performed using an ultrasonic measuring device type DMS-2-TC with an accuracy of 0.01 mm.

Fig. 7. Outside of the elbow

The wall thickness variation along lines 1 and 2 measured at distances of 50 mm are presented in Table 6.

Table 6. Values registered from the elbow thickness measurements

No.		Proper area *g* [mm]	Note
1	Line 1	6.42	
2		6.41	
3		6.61	
		Affected area *g* [mm]	It was noticed the material rupture without gradual thinning
8	Line 2	5.54	
		4.75	
		4.52 (near the defect)	
		penetrated	
		5.20	

In order to compare the experimental results with the results obtained by using equation (4) the erosion rate was calculated for the following process parameters:

W – sand rate 23.83 (kg/s);
V – air velocity 16 (m/s);
D – pipe diameter 0.1 (m);
d – particle diameter 560 x 10 $^{-6}$ (m);
ρ_m – mixture density 1300 (kg/m^3);
S_K – a geometric factor : 5.5 for elbows [10].

The erosion rate is:

$$ER = 435 \text{ x } \frac{23.83 \times 16^2 \times 560 \times 10^{-6}}{5.5 \times 0.1^2 \times 1300}$$

$$ER = 20.78 \text{ mm/year or } 6.16 \text{ mm/3 month}$$

As it can be seen, the empirical premises of the value of maximum wear rate registered during pneumatic sand conveying have been practically confirmed.

Because the basalt coated bend was subjected to a fast wear, different constructive options have been proposed to consider either reducing the sand particles direct impact on the bend in the curvature area, or using materials more resistant to wear.

Conclusions

In this paper the wear rate of elbows as components of sand pneumatic conveying equipment, was theoretical and experimentally investigated by measuring the wall thickness at different intervals.

The total wear after three month of sand conveying equals the total thickness of the steel elbow (7.1 mm).

The experimental results are in good agreement with the erosion rate calculated by using equation (4).

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Dinamica procesului de uzura în coturi în timpul transportului pneumatic al nisipului

Rezumat

Fenomenul de uzură abrazivă prin eroziune este specific transportului de nisip, atât în cazul transportului cu şnec elicoidal, cât şi al transportului pneumatic. La transportul pneumatic cele mai afectate sunt conductele şi coturile sistemului de transport.

Această lucrare prezintă rezultatele cercetării cu privire la dinamica procesului de uzură prin eroziune, care atinge cote maxime în zona de schimbare a direcției de curgere a amestecului, cum este cazul coturilor.

Dinamica procesului de uzură a fost evidențiată prin măsurarea peretului unui cot, aflat în exploatare pe linia de transport timp de 7 luni, în zona de maximă uzură. Măsuratorile înregistrate au fost comparate cu rezultatele obâinute empiric prin introducerea parametrilor care definesc condițiile de transport).

După cum se constată, rezultatele practice sunt în concordanță cu suportul teoretic.