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Use of spiral conveyor in the processing of granular waste materials

J. Sander[1*] and T. Jehlička[2]

[1]Czech University of Life Sciences Prague, Faculty of Engineering, Department of Technological Equipment of Buildings, Kamýcká 129, CZ 165 21 Prague 6 – Suchdol, Czech Republic
[2]Czech University of Life Sciences Prague, Faculty of Engineering, Department of Technological Equipment of Buildings, Kamýcká 129, CZ 165 21 Prague 6 – Suchdol, Czech Republic
[*]Correspondence: sander@tf.czu.cz

Abstract. The work presents a construction solution, verification of operation function and evaluation of the efficiency of a spiral separator in processing of agricultural, food industry and other granular waste. The common method of processing waste is based on crushing and subsequent sorting by various physical and mechanical properties. Crushing waste results in a heterogeneous mix of particles with a substantial size and weight difference and major share of dangerous powder particles. Thus, specific requirements are put on the conveying and manipulation of the mixture. The solution is using pneumatic conveying and closed sub-pressure separators. Under laboratory pilot conditions a sub-pressure spiral separator was designed and tested. The separator is designed as an immobile drum sieve in which a rotating axis-free helix is inserted. The inside space of the drum sieve is linked axially to the sub-pressure pipe of the combined conveyor. A light aspiration proportion (dust particles) are carried by the air flow while the granular particles with big specific weight and specified size make the sieve fraction. The particles larger than the separation apertures of the sieve are carried mechanically by the helix. The separating efficiency was observed on a mix of granular materials at same operation conditions. The contents of the mix of granular materials varied in size, specific weight and in the proportion of dust particles. Evaluation of the separating possibilities of the spiral separator verified the operation applicability of the system for separation and conveying of various agricultural, food and other granular materials.

Key words: pneumatic conveying, mechanical conveying, granular waste, separation, combined transport materials.

INTRODUCTION

Conveying and sorting granular materials is a frequently applied technological process in agriculture, food industry but even in waste management. Systems using gravitation, mechanical conveyors or pneumatic or fluid equipment are employed. The use of a particular equipment is always linked to conveying conditions and to properties of the material conveyed.

Products of variable physical and chemical properties originate during waste processing. Such products result from crushing. In practical application it is a mixture of substances of different specific weight, granuity, or extremely dusty materials which are contaminated microbially, or are toxic. This provides elementary requirements for transport and further processing of such products. Conveying facilities must allow for both vertical and horizontal directions. They must be airtight due to dust and they must be able to convey granular material with high difference in specific weight at minimum energy requirements. Equal conditions apply for separating and sorting processes which are an inseparable part of waste processing. Pneumatic conveying in the form of closed pipelines is applied in waste processing where the material is conveyed by overpressure or by sub-pressure of the air sucked and then released into the conveyor environment. With materials of high difference in specific weight such conveying has its limits. Practically it entails the necessity to use lower pressure and smaller flow of the air volume which result in shortening the conveying distance, lowering the conveying elevation, reducing efficiency or to limiting the different in the material thus conveyed.

There is a variety of ways how to reduce the indicated shortcomings of low-pressure pneumatic conveying with maintaining the project requirements of the function of the processing lines. There is a possibility to change the properties of the material conveyed (pre-sorting and reducing the size and weight difference of the conveyed particles) or to adjust the parameters of the conveying system (increasing the volume of the air flow and pressure). Changing the material properties or adjusting the parameters of the conveying system can be used only to a relatively limited extent in the low-pressure pneumatic conveying and at the cost of a relatively higher energy requirements (Yan et. al., 2012). For this reason a solution based on combination of separated pneumatic and mechanical conveying hereinafter combined conveying was suggested. The mechanical part of the conveying deals with the higher weight and volume of the materials, with the conveying elevation and it lowers the energy requirements and technical limitations of pneumatic conveying. It has, however, greater requirements of space, the wear is quicker and there is a necessity of tuning together the pneumatic and mechanical part of the conveying path.

Operational tests of the suggested construction of a combined conveying of granular materials have confirmed the expected construction insufficiencies – namely the mechanical wear of the combined conveyor in a long-term operation. One of the reasons of the wear were the solid particles of higher weight with size close to the difference between the inside diameter of the conveyor pipeline and the outside diameter of the axis-less helix. The particles were further crushed inside the conveying path and the load of the mechanical part of the conveying path increased due to higher friction. The newly designed construction suggests to incorporate a mesh separator at the beginning of the conveying path of the body of the combined conveyor which will pre-sort the material conveyed. The design uses a part of the conveyor to be used for pushing the material through the mesh separator. The aim was to preserve every advantage of the combined conveying and increase the conveyor capacity, efficiency and reliability without any further space requirements of the line construction (Mills, 2004).

The present work follows the design of the construction of combined conveying (pneumatic and mechanical) in processing granular materials. It complements the equipment with a possibility of separation of a part of the conveyed mix as early as at the conveying and it verifies the operational functions of the separator while maintaining the operational properties of the combined conveyor.

MATERIALS AND METHODS

A mesh separator prepositioned and mechanically linked with a combined separator was designed and tested under laboratory pilot conditions. Conveying possibilities of this combined conveyor for granular waste materials with various specific weight and size of the particles have been evaluated.

The work has been carried out on the pilot line for electrical waste processing. The line was situated in the laboratories of the Czech University of Life Sciences Prague.

Brief description of arrangement and function of the line for electrical waste processing

The electrical waste is crushed in the bi-rotor crusher and further in a knife-mill. The crushed material and the dust are carried into the following conveyor pipeline of the combined conveyor where the small particles of higher weight (the medium fraction) are separated on the mesh separator. The larger particles and the dust are further conveyed by a combined conveyor into the dust separator where the dust is removed. The dust-free material is transported via a magnetic separator onto the fluid table where it is sorted by its specific weight. The spiral separator then pre-sorts the conveyed material by the set size depending on the mesh used. After magnetic separation this medium fraction is moved for further processing outside the line depending on the character of the material processed.

Design and execution of combined (pneumatic and mechanical) conveyor system

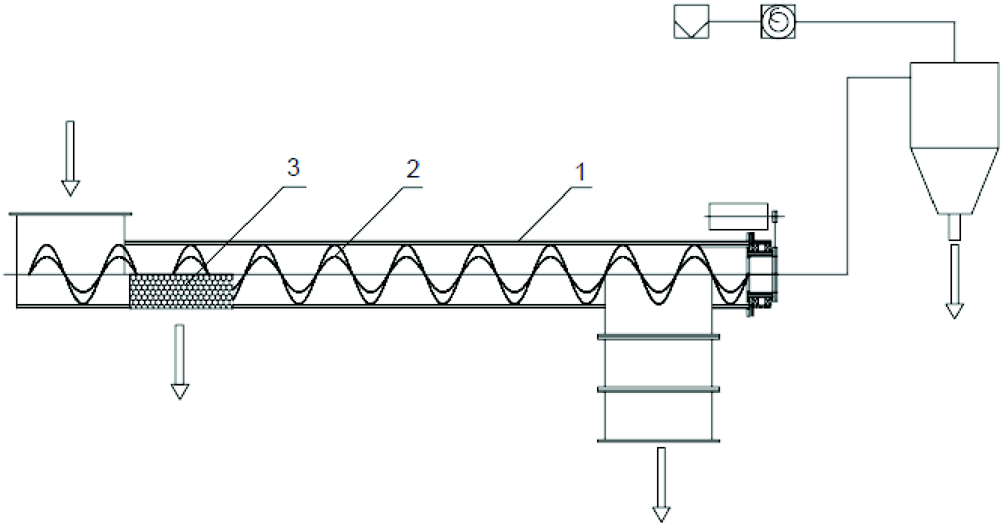
The construction is a conveying pipeline of circular diameter at 150 mm for low-pressure pneumatic conveying inserted into the inside of the pipeline in combination with the mechanical driving element in the form of an axis-free helix. Within such space the material is transported as a result of the dynamic effects of the flowing medium and at the same time it is driven mechanically by the rotating axis-free helix. A radial ventilator URBAN Technik, Type VE-6000 A is the source of negative pressure with an output of 4,500 $m^3 h^{-1}$ and with operating negative pressure of 400 Pa. This technical solution allows for pneumatic and mechanical conveying in a single conveying space (conveyor pipeline).

Particles with lower specific weight and with greater aerodynamic resistance are carried by the airflow mainly through the centre of the pipeline. High specific weight particles are moved mechanically by the energy of the axis-free helix. Such construction of the conveyor pneumatic pipeline can be used on short distances both horizontally and obliquely (Jehlička & Sander, 2015).

Spiral separator description

A mesh with pre-defined apertures was placed on the bottom of the combined conveyor 50 cm from the opening of the combined conveyor pipeline. During the movement of the granular mix carried from the opening of the combined conveyor the separation of a part of the conveyed granular material with higher mass occurs according to the size of the mesh apertures.

Particles with lower mass and larger size and the dust particles are moved by the combined conveyor further to the dust separator. Mesh made from perforated metal sheets with circular openings at 6 and 8 mm was used for separation. The minimum size of the mesh apertures must be larger than the difference between the inner diameter of the pipeline and the outer diameter of the axis-less helix. A simple diagram of the separator is in Fig. 1.



1 – pipeline; 2 – axis-less helix; 3 – mesh

Figure 1. Schematic diagram of the spiral separator.

Spiral separator operation function verification

Verification of operational function (efficiency of the separation process) was carried out by a comparison of the percentage of the volume of separated particles of the material conveyed on the mesh separator with the volume of particles of the same size in the outlet of the combined conveyor. The efficiency of the process of separation (ability to separate the material of the given physical properties at the operational conditions thus set) used in combined conveying of granular materials is affected by a number of factors. The pneumatic part of the conveyor is affected considerably by the gravitation effect during the adherence of the air through the mesh apertures. Reverse adherence of the air into the conveying path affects the function of the pneumatic part of the conveyor in front of the separator. Therefore the measuring was first carried out while the pneumatic conveying was turned off. The size of the separator mesh was by experimentation set so as, with minimum size of the mesh, the separation efficiency was maximum at the atmospheric pressure.

With the pneumatic section on, the pressure was gradually set to values which were used in the reliability measuring of the pneumatic conveying without the mechanical conveyor, including the pressure which secured conveying reliability of the combined conveying of the granular materials used without inserted separator in previous measurements (Mallick & Wypych, 2009).

The dry crushed mix used in the measurement consisted of two kinds of granular material which differed in granularity and specific weight. The same mixture was used in the measurement of reliability of the pneumatic and mechanical conveying. The mixture was created by the crushing and sorting of electric cables (electrical waste). The former material was metal (electric conductor) sorted into several groups by grain size. The other material was the share of plastics (electrical insulators). Efficiency of the separation process was observed for particles with higher mass (electric conductor) and the size coming close to the difference between the inner diameter of the conveying pipeline and the outer diameter of the axis-free helix, in this case 4 to 6 mm (the size of the apertures 6 and 8 mm). Operational conditions were set by the pressure in the conveyor pipeline according to the previous measurements on the combined conveyor less the separator. The pressure was changed step by step by setting the ventilator revs. The operational pressure was measured by a measurement device Testo 521-1 (equipped with external piezoresistive probe of 0 to 2,000 hPa; labelled 0638 1847) with a pressure sensor located in the conveying pipeline at 1.9 m from the separator (constant air flow) (Baker & Klinzing, 1999). The atmospheric pressure at the time of measurement was 1,015 hPa. The weighting method was selected for the evaluation of the separation efficiency. The measured mixture was weighted in front of the conveyor, after the mesh separator and at the exit of the combined conveyor.

RESULTS AND DISCUSSION

The measuring is always carried out repeatedly for separate values of operation pressure. The percentage of separated particles with set operating pressure within the conveying pipeline at constant conveying reliability of the combined conveyor i.e. reliable conveying of the remaining part of measuring mixture was observed. The average values of repeated measuring of the separation are recorded in Table 1 and 2. The size of separated particles was 4 and 6 mm of metallic fraction (electric conductor). Table 1 for mesh apertures of 6 mm. Table 2 for mesh apertures of 8mm.

Table 1. Operation pressure values of 4 and 6 mm particles separation, mesh 6 mm

	Granuity of mixture 4 mm	Granuity of mixture 6 mm
Pressure (hPa)	% separation	% separation
1,015	95	83
980	94	81
970	94	79
955	93	77
940	92	76
930	90	75
920	87	74
900	85	72

Table 2. Operation pressure values of 4 and 6 mm particles separation, mesh 8 mm

	Granuity of mixture 4 mm	Granuity of mixture 6 mm
Pressure (hPa)	% separation	% separation
1,015	95	95
980	94	94
970	93	93
955	92	92
940	90	91
930	89	90
920	89	90
900	87	88

The correlation of observed factors are brought into figures and interspersed with trend line. Fig. 2 represents the values of Table. 1. The Fig. 3 represents the values of Table 2.

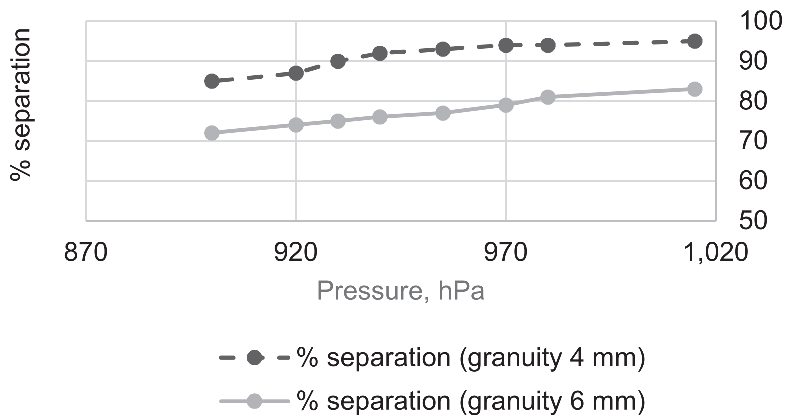


Figure 2. The dependence of separation efficiency on the operating pressure 6 mm mesh.

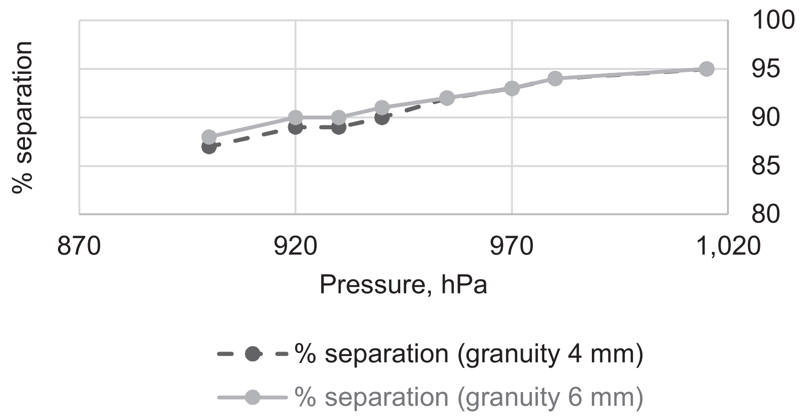


Figure 3. The dependence of separation efficiency on the operating pressure, 8 mm mesh.

The progress of separation efficiency within the range of pressure values, at which the conveying reliability of the combined conveyor without separator was verified, is apparent from acquired curves.

Given pressure value corresponds always corresponds to minimum at which the material particles were reliably conveyed. Pre-sorted mixture of crushed conductors with granuity of 4 and 6 mm was used due to the measuring accuracy of the separation mesh effectiveness.

Conclusions of measurement:

– A slight shift in the direction of the spiral rotation occurs during the movement of the measured mixture. Therefore, the mesh was placed with shift of 25 degrees from the vertical axis in order to increase the separation efficiency.

– Variable size of the mesh for assorted types of separated mixture will be required in operation conditions. The cylindrical mesh with variable aperture would be the solution.

– The measurement of efficiency at 6 mm granuity in mesh with 6 mm aperture – hexagonal apertures of the mesh will improve the separation efficiency for particles of the mixture with size close to the aperture size.

The verification of energy consumption was carried out by measuring the power input at the clamps of the electric motor of the traction spiral drive. The power input was measured with covered and exposed mesh. This method is purely orientational n dis dependent on sub-pressure and the amount of separated mixture. Therefore the measured values are not presented here. Solely the reduction of energy consumption was verified. Used method is sufficient for the verification of presumptive energy influence of mesh separator introduced into the conveyor (Hilgraf, 1998).

The measuring was carried out at laboratory equipment, therefore it largely applied only to the verification of the function. With industry prototype it would be possible to carry out more accurate measurements of properties and regulation options of the spiral separator system. Various problems can be presumed in case of real operation.

CONCLUSIONS

Constructional solution, which is proposed and verifies by the paper, is a reaction to conveying difficulties in long-term operation of combined conveyor for dry loose mixtures with high difference in mass. The operational wear of the conveyor and the operational vibrations were eliminated using the mesh separator with the combined conveyor in combination and simultaneously the premise of energy consumption reduction was proven. Elevated friction and further crushing of conveyed material due to particles the size of which is close to the gap size between the circumference of the conveying spiral and the conveyor tube were eliminated. All premises were verified by operation test and measuring.

The combined conveyor accompanied by mesh separator became a separation equipment with conveying of material. By its functional principle it divides conveyed material into three fractions. The fraction of light particles is separated by pneumatic conveying (light fraction). Whereas the fraction of particles with mass higher than the carrying force of the pneumatic conveying was mechanically separated by the conveying spiral (heavy fraction). The divide between these fractions varied according to the setting of production parameters of the pneumatic conveying and according to the nature of conveyed mixture. A third (medium fraction) was created by insertion of mesh separator. Thus the equipment was transformed into pneumatic spiral separator with separation of three fractions the function of which was verified by measuring and pilot production using the mixture of electric waste. With measured mixture, the interaction of pneumatic conveying and mesh separation was minimal and it may be adjusted by proposed means.

The separation of medium fraction itself eliminated the sensitivity of the pneumatic conveying setting. By simple overlaying of the mesh the equipment can then serve as a conveyor or separator. Proposed combined conveying with separation is structurally simple, reduces total energy used for material conveying, has minimal built-up area requirements (tension member is inside the conveying pipeline) and low number of moving parts.

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