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Operation of pneumatic conveying systems in technological processes

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Abstract

The use of energy from the pneumatically conveyed bulk material has become an essential part of technological processes in various branches of production industries. In foundry industry the pneumatic conveying systems, mostly high-pressure conveying, are used in such processes as injection of dry bulk material into liquid fluid, moulding sand reclamation, shortcreting of thermal equipment, burdening and feeding in mixing processes. Also, pneumatic conveying can be used in mining, industries of construction materials, chemical engineering as well as power sector.

Key words: conveying, bulk material, intensification of foundry processes, mining, construction industry, chemistry

1. Introduction

Pneumatic conveying involves moving of bulk material in a stream of various carrier gases in closed tubes (pipelines). For the last several years this discipline has revealed a very dynamic development. This results from the development and modernisation of feeding devices as well as electronic control devices that support the operation in fully automatic cycles. Thanks to this we can design areas for reloading and conveying of materials to receiving devices where human interference is no longer needed. Moreover, the undisputed benefit of pneumatic conveying is the hermeticity of conveying and receiving bulk material. The already mentioned advantages have become the grounds for it gaining its popularity among various industrial applications. Currently it is used in foundry industry for the injection of powders into liquid metal as well as moulding sand reclamation, modification and refining of alloys and production of liquid dispersion composites. In food, chemical and

pharmaceutics industries this type of conveying is used for conveying of materials, their mixing and dosing. In mining and construction industry - for shortcreting and production of plaster and construction cements. The development of these methods largely depends on the intensity of research meant to define the usability of specific materials for pneumatic conveying, selection of optimal parameters of conveying (rate flow of gas and material) and implementation of improved design solutions of feeders, control valves, receiving devices, filters, etc. This research is carried out at laboratory conditions in a significantly smaller scale, and its results by means of dimensionless numbers are later shifted to real systems. This is of real significance as in many cases it has become possible to carry out the analysis of usability of specific type of feeders for conveying of specific material as early as at the initial stage. For many years the Silesian University of Technology has been the main implementation and development centre of pneumatic conveying.

Flow structure. The structure of diphasic flow of solids and gas in conveying tubes depends mainly on the flow rate of each phase, concentration of solids in the conveying agent and physical and chemical characteristics of the conveyed material (size and shape of particulates and their terminal velocity).

For simplification the flow structure has been presented with reference to the diphasic flow of solids and carrier gas. During the joint flow of both phases we can observe mutual interaction between the particles of the solid phase as well as the impact of both phases on the conveying tube. The structure of the diphasic flow is also shaped by the manner and amount of particles of solid phase in a gas stream introduced simultaneously into the conveying tube. For the quality description of flow structures in pneumatic conveying systems we use dependences between the average gas rate referred to the pipeline cross-section ($w = \sqrt{\Delta p/l}$) and pressure drop of the conveyed gas per the pipeline unit length ($\Delta p/l$). Fig. 1 presents this dependency for vertical conveying of bulk material. A similar graph describes horizontal pneumatic conveying.

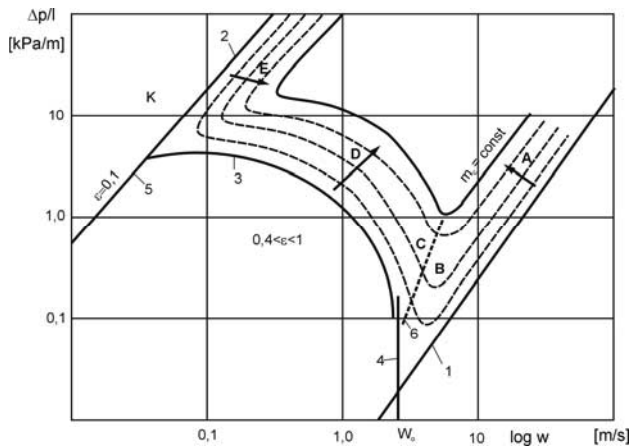


Fig. 1 Types of diphasic flow of pneumatic conveying of bulk material. 1-flow of gas only, 2-pipeline fully filled with bulk material, 3-flow through a layer of fluidized material, 4-flow with terminal velocity of material particles, 5-gas flow through slugs, 6-area of stable operation of layer conveying, A-flow with settling of dispersed solid phase, B-layer flow, C-portion flow, D-fluidized flow, E-force flow [1]

Pneumatic conveying is possible within curve boundaries 1, 2, 3, 4 (fig. 1). Individual curves characterize unitary pressure drops ($\Delta p/l$) at the flow of gas only (curve 1) and through a pipeline fully filled with bulk material (curve 2). Extreme boundaries define the flow through a layer of fluidized material (curve 3) and through the pipeline with terminal velocity comparable to terminal velocity of material particles (line 4). Boundary line 5 indicates the route of pressure drop per height unit of fixed layer (slugs, $\varepsilon \sim 0.4$) at the increase of flow rate of fluidized gas. At w_k gas velocity called critical, there occurs a change of fixed layer of material into fluid layer. A characteristic feature of fluidized layer is an almost constant pressure drop at the increase of velocity of fluidized gas. With

the further growth of gas velocity the concentration of fluidized layer and pressure drop per unit of layer height are decreasing in accordance with curve 3 route. When gas velocity makes even with free particle terminal velocity (w_0), there occurs a boundary condition, where fluidisation is finite ($\varepsilon = 1$).

In the area of operation of pneumatic conveying (fig.1), depending on the mixture concentration and velocity, we distinguish the following types of flow: A – with settlement of dispersed solid phase, B – layer, C – portion, D – fluidized, E – force.

The systematics of pneumatic conveying is based on the amount of pressure of feeding gas, structure (form) of diphasic flow of solid and gas particles and characteristics of the conveyed material. We distinguish two main groups of conveyors: sucking (underpressure) and forcing (overpressure).

With regard to the amount of applied pressures we distinguish low-, mid- and high-pressure conveyors.

Low-pressure conveyors - feeding with air at pressure $p_n < 0.02$ MPa produced by high-pressure ventilator and mid-pressure ones at compression $p_n = 0.02 - 0.08$ MPa produced by blower. They are used for the conveying of fine granular bulk material of low bulk density ($\rho_u < 600$ kg/m³).

High-pressure conveyors - operate at pressure $p_n = 0.3 - 0.8$ MPa produced by compressor, are used for the conveying of dry and humid bulk material of different granular fraction, not exceeding 1/3 diameter of conveying pipeline.

2.Characteristics of conveyed material

The characteristics of bulk material defining its usability for pneumatic conveying depend on: grain size, their shape and fraction homogeneity, gas humidity and viscosity, etc. Most of the conveyed materials is of a granular form (mostly multifractional), i.e. a set of particles being different in size and shape. The proportion of a given volume of material particles to its surface has impact on the amount of flow resistance and at the same time it is crucial in the selection of the conveying type. The changes in the distribution of size and shape of particles affect also the scope of technological usability of a specific material [2].

Humidity of the conveyed material. Particles of humid material, and in particular in connection with binding agents (mostly binder), indicate capability to join into bigger agglomerates. This type of material has a tendency to plug the inner surface of the conveying pipeline, reducing gradually its cross-section.

Grain strength. This parameter is significant for the establishing of the maximum conveying velocity of specific granular material, at which the particles do not crumble. The constancy of granular fraction during conveying ensures constant flow resistance, and frequently decides about the technological usability of material conveying system devices.

Hardness of particles of a specific material constitute a basic criterion for the assessment of its erosive impact on the conveying pipeline during pneumatic conveying. At high hardness of particles of the conveyed material, the intensity of erosive impact increases with the growth of velocity of the flow of solid state. The hardness of material particles and their conveying velocity have a crucial impact on the durability of the

conveying line. Decreasing the erosive impact of particles of specific hardness can be gained by reducing to the required minimum of the stream velocity in the pipeline, using most frequently the fluidized force and gravitation conveying and layered force conveying.

Temperature of the conveyed material is of a large significance in adapting and equipping the conveying line, especially the sealing, drive and control elements.

Fluidity of material. This characteristics refers to a small amount of dry materials, in general of the fraction of less than 20 μm , which after aeration as a result of reducing the internal friction coefficient assume properties of fluids. Maintaining the material in a fluid state requires a constant saturation of the material with flowing gas. This group of fluidizing materials includes: cement, lime, coal dust, bentonite, fine granular sand, anhydrite, smoke dust, etc.

Density of material particles jointly with their size and shape is a decisive factor for the velocity of the conveyed material in a gas stream.

The scope of applications of conveyors depends on the type of conveyed material as well as on the given conveying efficiency and distance.

Pneumatically conveyed materials can be of various characteristics, therefore the scope of applications of a selected type of conveying is very restricted. Pneumatic conveying of solid particles in a dispersed state in area A, B (fig. 1), taking into account the variability of materials, cost and distance of conveying, has the widest scope of applications. For the purposes of conveying various types of materials in one plant, due to technical and organisational reasons, only one conveying system is used.

3. Pneumatic conveying in technological processes

Moving of bulk material in pneumatic systems depends on the takes place using gas (air) stream energy. The extent of dispersion of bulk material in a conveying tube depends on quality parameters of the transported agent and complex technical and technological conditions. The high-pressure pneumatic conveying enables to control concentration of material and conveying agent in the pipeline as well as the velocity of the diphase stream [3].

Solutions of conveying lines on the basis of pneumatic system devices can be used not only for the conveying of bulk material but also for the performance of technological processes. These conditions are met by system devices characterised by versatility in the scope of installing conveying lines (pipelines), their leak tightness and possibility of a fully automatic control of the conveying process. The effectiveness of the diphase stream flow (air and bulk material) depends on the parameters of feeding of the conveying line adapted to the requirements of operation. The interrelation of these parameters with the operational assumptions for the installation i.e. with the required mixture concentration, stream velocity, structure of bulk material and the design of conveying line decide about the appropriate conveying process adapted to the processes of injecting bulk material to metal bath in metallurgy, moulding

sand reclamation in foundry, fuel desulphurization in power industry and protective coating (shotcreting) in metallurgy, mining and construction industry.

The proper and stable diphase stream flow of the mixture of material and carrier gas depends on carrier gas mass flow (stream velocity) and mixture concentration with given installation operating condition. These parameters in the solutions of high pressure pneumatic conveying can be controlled in a simple manner within a wide scope.

Pneumatic conveying feeding devices (chamber feeders) enable the following performance of technological processes:

- injection of powdered materials to metal bath in order to supplement the composition or change the structure of cast material,
- modification and refining of alloys and production of liquid dispersion composites,
- injecting bulk material to liquid with simultaneous mixing,
- moulding sand reclamation in foundry,
- protective coating (shotcreting) of site surfaces in order to achieve the required insulating conditions (thermal, anticorrosive, surface levelling) in mining, metallurgy and construction industry,
- fuel desulphurization in power industry,
- feeding bulk material with weighing precision of up to 0.1%,
- mixing of several bulk components in the conveying process without additional mechanical devices,
- abrasive stream treatment of the cleaned elements.

Injecting of powdered materials to liquid metal may be carried out in a melting furnace, casting ladle or pouring spout, This enables the processes of carburizing, dephosphorization, desulfurization, deoxidation or modification of metal bath.

Usability of the method of powder injection. The method of injecting powdered material into metal bath has found the following applications [8]:

- carburizing of liquid metal in electric arc furnaces and cupolas ,
- desulfurization and dephosphorization in ladles and electric arc furnaces,
- blowing alloying agents into liquid metal in ladles, electric arc furnaces and cupolas,
- modification and refining of alloys and production of liquid dispersion composites,
- injecting modifying agents onto the liquid metal stream in casting processes,
- expanding the slag in electric arc furnaces at steel melting,
- recycling of dust from dedusting of electric arc furnaces and cupolas,
- blowing coal dust into blast furnaces,
- blowing plastics for treatment in blast furnaces.

In many cases joining of the processes is also possible for example expanding the slag and dust recycling, carburizing in cupolas and dust blowing, the blowing of coal and plastics into blast furnace, infecting alloying agents and desulfurization). Below some of these applications have been described.

Carburizing of liquid metal. One of the main issues at cast iron melting in electric arc furnaces is obtaining the appropriate coal content in liquid metal. This is the most significant issue in many modern foundries which curtailed crude oil or resigned

from tit in stock material due to its high price. Therefore some attempts have taken place to replace this shortage of coal with traditional methods (adding carbourizer to stock material or further supplementing at the final stage of melting by casting on surface). These, however, are time consuming and low effective methods, strongly extending the time of melting. A far more effective solution is a method of pneumatic carburizing of liquid metal [3,4].

The main element of the stand for the carburizing process is a pressure vessel 1 (fig.2) of the volume of 0.25–1.0 m³ [5]. In its upper part the vessel contains a bell closing valve and in the bottom part - a mixing chamber. 3. The presser vessel 1 is contains vent valve for decompression of vessel after completing each cycle of operation.. Air pressure supplied to thee vessel over the conveyed material is controlled by reducer 4. Supplying and cutting off the air is possible through main reducer 10. All valves can be activated from the vessel control board 2 from the control panel in the furnace control room. The vessel is mounted on tensometric weight 5 and its results appear on control board 2.

Carbourizer is conveyed through conveying tube 11 finished with lance 13 and introduced to arc furnace 14 and immersed in liquid metal. Lance can be placed on manipulator 12, enabling its automatic immersion in liquid metal. This support the operation while ensuring protection and guaranteeing the repetitive character of the process.

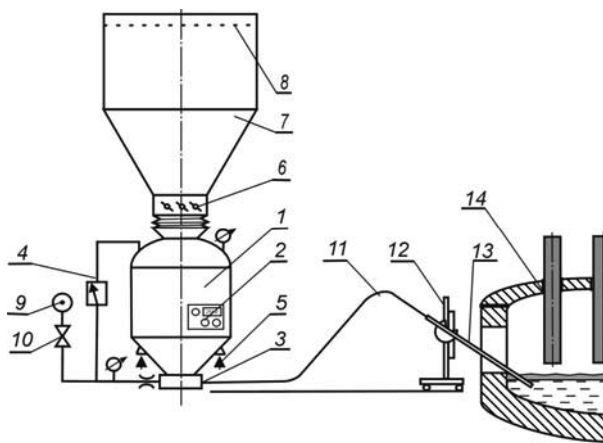


Fig. 2 Scheme of the stand for carburizing metal bath in electric arc furnace. 1-pressure vessel, 2- control board, 3- mixing chamber, 4-reducer, 5-tensometric weight, 6-damper, 7-storage container, 8-sieve, 9-compressed air feeding source, 10-cut-off valve, 11-conveying tube, 12-lance manipulator.

Over the device there can be storage vessel 7 for carbourizer of the volume designed for daily or shift use of carbourizer. In the upper part of the vessel there is a place for sieve 8, eliminating oversize particles and impurities from the carbourizer. The bottom part of vessel 7 is damper 6 (slot or swivel) driven by a pneumatic actuator. Between damper 6 and chamber feeder 1 it is necessary to install a compressor eliminating the impact of storage container on the weighing system.

In the feeding part there is an air filter installed, eliminating water and oil impurities.

Carbourizer is usually supplied by producers in big-bags of the volume of 1 m³. The most frequent carbourizers include electrographite, natural graphite, calcined anthracite and calcined petroleum coke. A good carbourizer should have a high coal content (> 95% C), low ash content, low sulphurcontent (< 0.3% S), especially for spheroidal iron, and volatile elements (< 1%), also, its humidity should not exceed the value of 0.9%.

Ash hinders coal moistening and diffusion, increase the amount of slag, reduced durability of lining and increases the use of electrical power. The increased amount of volatile elements (including oxygen and hydrogen,) causes the emission of impurities and increases the risk of porosity in casting.

The reclamation process involves cleaning the sand grain surface from the residuals of the used binder and removing fine dust fractions contaminating the reclaim. The result of moulding sand reclamation is the recovery of around 85% of the basic component with parameters enabling its reuse. The system of devices adapted to pneumatic moulding sand reclamation can be seen at fig. 3 [6].

The pneumatic transport devices may be adapted to many technological processes in almost each branch of industry (metallurgy, mining, chemical engineering, construction industry, food and pharmaceutical industry, etc.)

Versatile applications of the analyzed solutions result from the construction characteristics of the feeding devices (pneumatic conveying high-pressure chamber feeder).

Expanding the slag and flue dust injection. This method is based on the injection of powdered fly-ash, coal or graphite in an air stream, sometimes with an additional oxygen supply. It uses a chemical method of increasing gas phase density in a liquid phase, and therefore the product of oxygen and coal reaction, staying at metal-slag phase boundaries. For the economic reasons, during steel melting the arc furnace requires operation at the possible lowest current voltage at the transformer, and at the same time at lowest current voltage at electrodes i.e. at the so cold "long arcs". At the same time we get heat from chemical reaction, which protects electrodes from lateral oxidation and reduces their consumption. An additional advantage of this process is FeO reduction from slag and transforming Fe into liquid metal [7,8]. The consumption of coal material amounts up to 5 kg at 1Mg of liquid metal.

It is more and more frequent that the pneumatic method of conveying bulk material is also used for the treatment of waste material. Each metallurgical process taking place in any furnace generates a large amount of dust containing considerable amount of elements which can be recovered during the remelting process. To this material belongs steel dust from dry dedusting of volatile gases containing harmful Zn, Pb compounds and significant amounts of Fe compounds (30÷55%). Fig. 4 shows a system of devices used in the process of expanding the slag and infecting dust from arc furnace dedusting into liquid metal.

Mixing and fluidized segregation Many branches of industry require production of dry mixtures containing components that considerably differ in the size, shape and density of their grains. In this case the main criteria for the quality of this product is its homogeneity. Currently, out of many available solutions, very frequently the best one seems to be mixing of components in a fluidized bed [4].

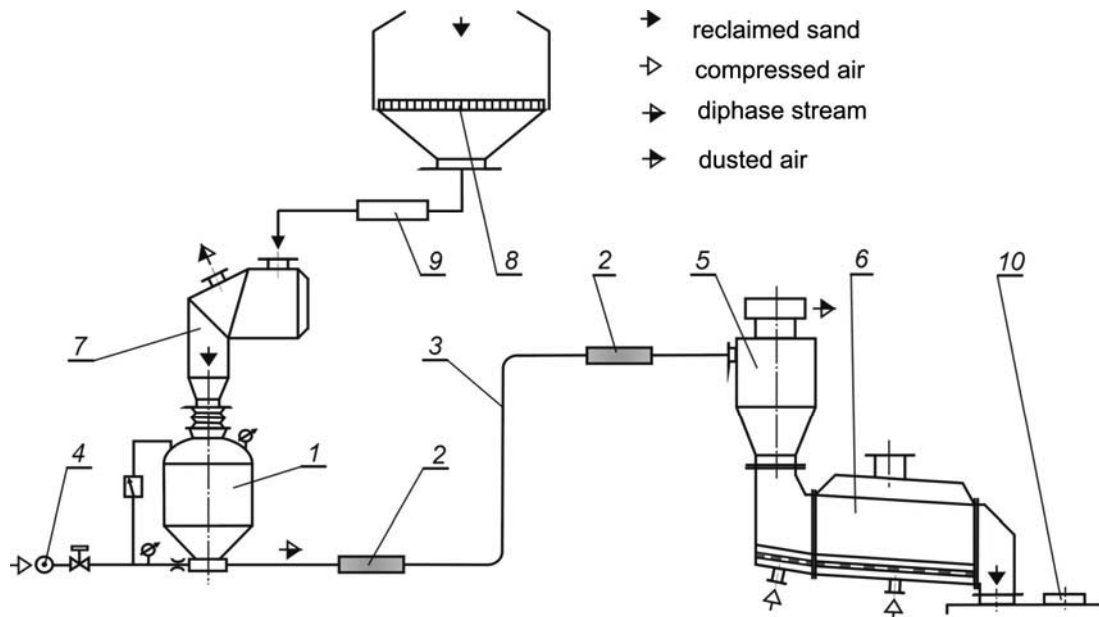


Fig. 3. Scheme of the system of devices of the pneumatic moulding sand reclamation. 1-pneumatic conveying feeding system, 2-linear regenerator, 3-conveying pipeline, 4-compressed air feeding, 5-system of receiving devices, 6-fluid classifier, 7-crushing and sieving devices, 8-devices for removing cast from moulds, 9-magnetic separator, 10-sand reclaim container

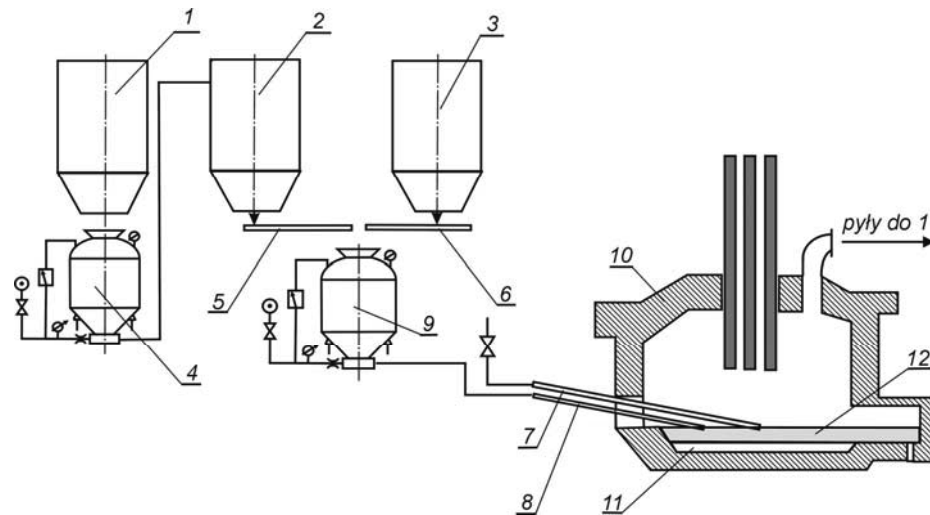


Fig. 4 - stand for coal and dust injection to electric arc furnace. 1-dust storage container, 2-intermediate dust container, 3-coal container, 4-chamber feeder, 5,6-screw feeders, 7-lance for oxygen injection, 8-lance for injection of powdered material, 9-chamber feeder of coal and dust mixture, 10-electric arc furnace, 11-liquid metal, 12-slag

The measure of the effectiveness of the mixing process is the level of homogeneity of the mixture in the whole volume, that is the equal distribution of individual components. Moreover, the effectiveness of the mixing process involves also its duration. Fluidized mixing seems to be an optimal solution for each of these parameters.

The solution of fluidized system of mixing components as shown at fig. 5 contributes to the increase of the effectiveness of

this process at variable properties of these components [5]. A model of such a system consists of vertical mixer 1 with hopper unit 6. In the bottom part of mixer 1 there is mixing chamber 2. Over feeding equipment there are component containers 10.

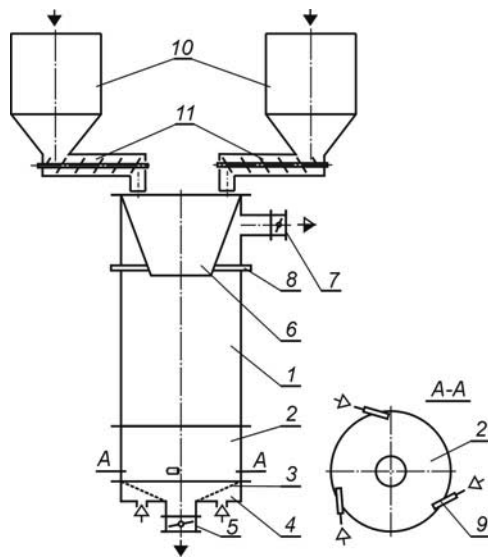


Fig. 5. Fluidized mixer of bulk material. 1-mixer, 2-mixing chamber, 3-porous insert, 4-air chamber, 5-compressed air supply, 6-hopper unit, 7-valve of dedusting device, 8-insert made of filtering fabric, 9-nozzles, 10-component containers, 11-screw feeders [5]

Bulk material is supplied to mixer 1 in appropriately proportioned amounts by screw feeders 11. The feeding unit is connected to dedusting valve 7. During the loading of components valve 7 is in open position. The area of fluidized mixing is separated from the dedusting part by insert 8 made of fabric with small flow resistance which enables the initial separation of dust from the mixing process.

The bottom dropping of mixer from chamber 1 follows the opening of valve 5. Its opening guarantees the complete emptying of chamber. The tilting of aeration insert 3 adapted to quality parameters of bulk components enables an effecting introduction of mixture. For bulk material (components) of qualities enabling the homogeneous fluidising from the whole density volume during air flow through the bulk, an optional solution is a nozzle unit supporting the mixing process. The dynamic air exhaustion from nozzles 9 may disturb the bed, which can stabilise itself after a specified period of fluidisation. The variable properties of mixing components may cause a secondary diffracting of bed. This is not beneficial regarding the homogeneity of the mixture.

The presented method of fluidized mixing and the equipment enables the production of a homogenous mixture in the whole volume of bed within a short time (from several and several tens of seconds). A selection of parameters of the compressed feeding the system depends on the properties of mixture components.

4. Summary

The energy of the diphas stream being a mixture of solids and conveying gas in dynamic transportation enables the adaptation of the conditions to the requirements of many technological processes. Besides the bulk material conveying there is also place for metallurgical processes. This includes the possibility of injecting crushed components into liquid materials such as liquid metal, chemical compounds or water in order to achieve the expected results. In metallurgy it is applied for the injecting of powdered material into the liquid alloys for the purpose of supplementing the composition or its stabilising (carburing, desulfurization, deoxidation, expanding the slag, etc). This process is also used in mining in grouting of gob (shotcreting), construction of backfill packs and air stoppings as well as for protections against coal dust explosion. In power industry pneumatic conveying is used for collection and conveying of ash from electrofilters to storage reservoirs.

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