Scale-up of Pneumatic Conveying Systems in Existing Plants

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Abstract

Due to their versatility, pneumatic conveying systems are in use in several bulk handling plants worldwide. With small mechanical changes existing plants can be upgraded or extended. The efficiency of the new version is then not in any case optimized. A simple model to scale up pneumatic conveying systems is described to verify the efficiency of newly modified conveying systems.

Based on given dimension and existing field data the energy consumption of a conveying plant is calculated first. Then the ideal version for the task is calculated and the two version are compared. The engineering model allows for an easy monitoring of existing and new systems.

Keywords: Pneumatic conveying, Energy efficiency.

1. Summary

A method for transferring the conveying pressure losses determined on a pneumatic test system to an operating system that differs in geometry and routing is presented. For this purpose, the $\overline{Fr}_R = \bar{v}_F^2/(g \cdot D_R)$ variation of the total test resistance coefficient, which is related to an average Froude number and depends on the pipe routing, is converted into a resistance coefficient of the solid that is (as far as possible) independent of the pipeline route $\bar{\lambda}_{S,h,V}(\overline{Fr}_R) = \bar{\lambda}_{S,h,B}(\overline{Fr}_R)$ and thus can be used for scale-up. From this, in turn, the respective total drag coefficient of the current plant $\lambda_{tot,B}$ can be determined, taking into account the course/characteristics of the operating system.

The procedure described is comprehensively illustrated on the basis of the measurement results of two bulk materials that are very different in their conveying behavior - wood powder and limestone powder. At the end a scale-up is done for an example with alumina.

2. Introduction

In the case of orientating conveying tests in a test plant (L_R, D_R), which are intended to assess the fundamental suitability of a new/not yet pneumatically conveyed bulk material, usually only the mass flows of solids $\dot{M}_S$ and conveyed gas $\dot{M}_F$ as well as the total pressure loss $|\Delta p_R|$ given back pressure p_{out} are usually measured as a function of the respective operating conditions at the beginning and end of the pipeline, i.e. the pressures (p_{in}, p_{out}), the gas velocities $(v_{F,in}, v_{F,out})$ and the loading $\mu = \dot{M}_S/\dot{M}_F$, with: $\dot{M}_S, \dot{M}_F =$ solids, gas mass flow, detected by measurement. The same conditions usually also apply to operating facilities in which the operator realizes different load cases, e.g., by varying the parameters mentioned. From the measured variables determined in this way, the adjusted pressure loss equation can be used to:

$$|\Delta p_R| = \lambda_{tot} \cdot \mu \cdot \frac{L_R}{D_R} \cdot \frac{\bar{\varrho}_F}{2} \cdot \bar{v}_F^2 \tag{1}$$

where:

Δp_R	Total pressure drop of conveying line, *bar*
λ_{tot}	Total resistance coefficient
μ	Specific load, *kg*
L_R	Length of piping, *m*
D_R	Diameter of piping, *mm*
$\bar{\varrho}_F$	Mean conveying gas density, *kg/m³*
$\bar{v}_F$	Mean "empty pipe velocity" of gas, *m/s*

An overall resistance coefficient λ_{tot} of the current production can be calculated. $\bar{v}_F$ is a suitably defined mean gas velocity, $\bar{\varrho}_F$ the corresponding mean conveying gas density. Both will be discussed in more detail. The λ_{tot}-values of the operating conditions examined at the test line describe their respective average pressure loss resistance and contain the individual resistances of the present conveyor line, i.e., they are pipeline-specific and cannot be used directly for the design of deviating conveying lines.

In the following, a method for transferring these "summarized" test results to operating systems is presented, which differ geometrically from the test routing, e.g., regarding pipe length L_R, pipe inner diameter D_R and/or route. The quality of the transfer is checked with the help of measurement results of the bulk materials wood flour and limestone powder.

The following stipulation applies:

- u_X refers to true velocities, "v_X" to so-called "empty pipe velocities. For the gas phase in pneumatic pipelines, for example $v_F = \varepsilon_F \cdot u_F$ applies, with ε_F relative voidage volume of the gas. Since such systems have values, $\varepsilon_F \gtrsim 0.90$. $u_F = v_F$ can generally be set with reasonable accuracy. In test evaluations in practice, this assumption is usually always used.

3. Pressure Loss Calculation of Pneumatic Conveying Lines

The following section introduces the equations required to calculate the pressure loss of pneumatic conveying lines. This is followed by a description of the usual procedure in practice for determining this total pressure loss.

The total pressure loss of a pipe consisting of horizontal and vertical pipe sections as well as the surrounding conveyor line is additively composed of the proportions of

$$\begin{gathered}\Delta p_R = \sum_{i=1}^{n} \Delta p_i = \Delta p_{S,f,h} \text{ (Solid friction horizontal) +} \\ \Delta p_{S,f,v} \text{ (Solid friction vertical) +} \\ \Delta p_{S,Hub} \text{ (Solids lifting) +} \\ \Delta p_{S,acc} \text{ (Solids Acceleration) +} \\ \sum \Delta p_{S,U} \text{ (Sum of solid deflections) +} \\ \Delta p_F \text{ (Conveying gas)}\end{gathered} \tag{2}$$

together. For the individual terms, cf. e.g., [1]. The terms in Equation (2) are described in the following sections.

Repeated insertion of the $\left|\Delta p_{R,B}\right|_{kor}$ value determined in each case as the new estimated/start value $\left|\Delta p_{R,B}\right|$ into the calculation process shown above leads to the results of the iteration summarized in Table 6. The following applies to all runs: $\overline{Fr}_{R,B} = 400 = const.$. After three iteration steps, the relative error is $(|\Delta p_R|_{kor} - |\Delta p_R|)/|\Delta p_R| < 0.002\%$. The iteration is cancelled, as no exact values can be read from the available $\bar{\lambda}_{S,h}$-diagram, see Figure 5. All data relevant to the system design is printed in bold.

Table 6. Iteration, Pipe $D_R = 143.0\ mm$, unstopped.

Step		$[Nr.]$	1	2	3
$\left\|\Delta p_{R,B}\right\|$		$[bar]$	0.400	0.456	0.458
$v_{F,in,B}$		$[m/s]$	20.01	19.64	**19.61**
$v_{F,out,B}$		$[m/s]$	28.02	28.59	**28.59**
$\dot{M}_{F,B}$		$[kg/h]$	1944.08	1983.63	**1983.83**
μ_B		$[kg_S/kg_F]$	4.63	4.54	**4.54**
$\bar{\lambda}_{S,h}$		$[1]$	0.0215	0.0215	**0.0215**
$\bar{\lambda}_F$		$[1]$	0.0140	0.0139	**0.0139**
$\lambda_{tot,B}$		$[1]$	0.0393	0.0394	**0.0394**
$\left\|\Delta p_{R,B}\right\|_{kor}$		$[bar]$	0.456	0.458	**0.458**

The calculation described can be accelerated using suitable iteration methods, e.g. selection of $\left|\Delta p_{R,B}\right|_{neu} = \left(\left|\Delta p_{R,B}\right|_{alt} + \left|\Delta p_{R,B}\right|_{kor}\right)/2$. Further information on the design of pneumatic conveyor systems includes [1, 4].

5. Conclusions

A method for transferring the conveying pressure losses determined on a pneumatic test system to an operating system that differs in geometry and routing is presented. For this purpose, the $\overline{Fr}_R = \bar{v}_F^2/(g \cdot D_R)$ variation of the total test resistance coefficient, which is related to an average Froude number and depends on the pipe routing, is converted into a resistance coefficient of the solid that is (as far as possible) independent of the pipeline route and thus can be used for scale-up. From this, in turn, the respective total drag coefficient of the current plant can be determined, taking into account the course/characteristics of the operating system. This allows for an easy scale up. If a system is well known in dimensions and operating data, it is possible to derive from this data the necessary resistance coefficients and design a conveying system.

6. References

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