A Taxonomy of Bulk Material Dosing Systems for Solid Recovered Fuels

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The proportioning of bulk materials is a key functional task within the overall process of cement manufacturing and all related transport and logistic systems. Solid recovered fuels are often characterised by their time variant bulk material properties, which often leads to a non-satisfying dosing accuracy, especially when the associated bulk handling installations are not adequately planned. Even if many different system architectures are proposed throughout the last decades, there is no systematic classification available, which allows a strategic decision for a specific methodology. This article proposes a general taxonomy for the classification of metering and dosing devices for bulk material. Based on the developed framework, an analysis of the typical range of products is carried out. Furthermore the novel ODM-WeighTUBE®, a tubular gravimetric high-precision dosing system, is introduced as an example for the latest developments within the field of bulk material proportioning.

Introduction

During the last decades DI MATTEO gained intense experience with the successful implementation of material handling solutions of alternative fuels, such as tire chips, animal meal or residue derived fuels (RDF), within the cement and power industry all over the world. One of the fundamental challenges faced during this period was and still is, the immense variety of the material properties (e.g. relative density, granularity, humidity, etc.) which need to be covered by all machineries delivered within a complete alternative fuel dosing plant. Especially the integration of reliable and accurate gravimetric dosing systems into conveying lines for alternative fuels need to address the issue of time-varying material prosperities carefully. In this context several different technologies for the metering of bulk material, such as belt weigh feeders or differential dosing units, have been applied in the past. The decision for a particular dosing technology depends mainly on the individual specifications of the solid fuel and the corresponding process requirements.
As an example especially the physical properties shall be briefly introduced here, where the Table 1 provides an overview of typical bulk material properties of solid alternative fuels (here: biomass and refuse-derived fuels (RDF)), as defined in [1]. It shall be mentioned that many of the characteristic values vary immensely over time and for different fuel suppliers. In Europe especially the moisture content within the solid fuel is often causing problems, especially if the corresponding storage and transport systems are not adequately chosen. Here the influence of time-consolidation and compactibility of the material are often underestimated (see [2]).

Within this context, it is also important to consider the long-term stability of the aforementioned characteristics, which is often underestimated during the design phase of bulk material handling systems, especially if there is a lack of experience with the utilisation of novel materials, e.g. during the introduction phase of new alternative or secondary fuels. Therefore, it is essential to start the systematic selection of adequate dosing equipment with a holistic approach towards the exact characterisation of the bulk material by means of mechanical, chemical and other relevant evaluation methods. It is also noteworthy, that the actual process requirements of the proportioning process can also be completely different, depending on where the system shall be installed within the complete manufacturing and logistic process chain. Very important within this context are quite often also legal requirements which need to be fulfilled due to quite strict international standards and quality management procedures.

Table 1 – Typical physical properties of solid alternative fuels

Typical data		Comparison	Europe		Middle East	
		Coal	Biomass	RDF	Biomass	RDF
Bulk density ρ	kg/m³	500 - 800	270 - 590	80 - 230	70 - 180	80 – 220
Moisture content	%	< 15	< 35	2	< 10	< 20
Particle size (2D)	mm	< 1	< 200	< 50	< 100	< 50
Compressibility index	-	1,0 – 1,2	1,2 – 3,0	2,5 – 4,0	5,0 – 8,0	3,0 – 5,5
Flow properties	-	free flowing …	bad flowing, fibrous, affinity for arching, time consolidating			
Explosion and fire requirements	-	yes	to be evaluated individually, in general to be considered			

If all above mentioned boundary conditions are well defined, it is still not guaranteed, that the actual task of choosing and integrating the optimal corresponding dosing equipment can be completed successfully, since it is observable that the decision for one or other solution is not following clear rational guidelines, but more fuzzy decision factors. A typical example for such a misconception during the planning and installation of dosing equipment is the transfer of positive or negative operational experiences with a particular piece of equipment from a quite specific field of application to a completely different scenario. Such an ill-posed transfer of experience is a typical trap during all conceptual phases of modern engineering, since it is contrary to a logical and rational selection of the optimal equipment.

DI MATTEO developed since its establishment in 1961 an immense experience with the implementation of all kinds of proportioning devices for a great variety of bulk materials in numerous different application fields. From the efficient feeding of alternative fuels (AFs) (e.g. RDF, shredded tyres, sewage sludge, etc.), over the classical dosing of raw materials (limestone, clay, sand, iron ore, etc.) to the implementation of all kinds of weighing hoppers and silos, all types of possible projects were already successfully engineered and realised in cement plants, steel factories and power plants all over the world. Furthermore, the company acted also as a driver of innovation within this field, with the successful introduction of the award-winning patented new tubular gravimetric dosing system ODM-WeighTUBE® (see [3]), and the development of the modular and comprehensive ODM-GravitAS control platform and software library, as introduced in [4] (see Figure 1).

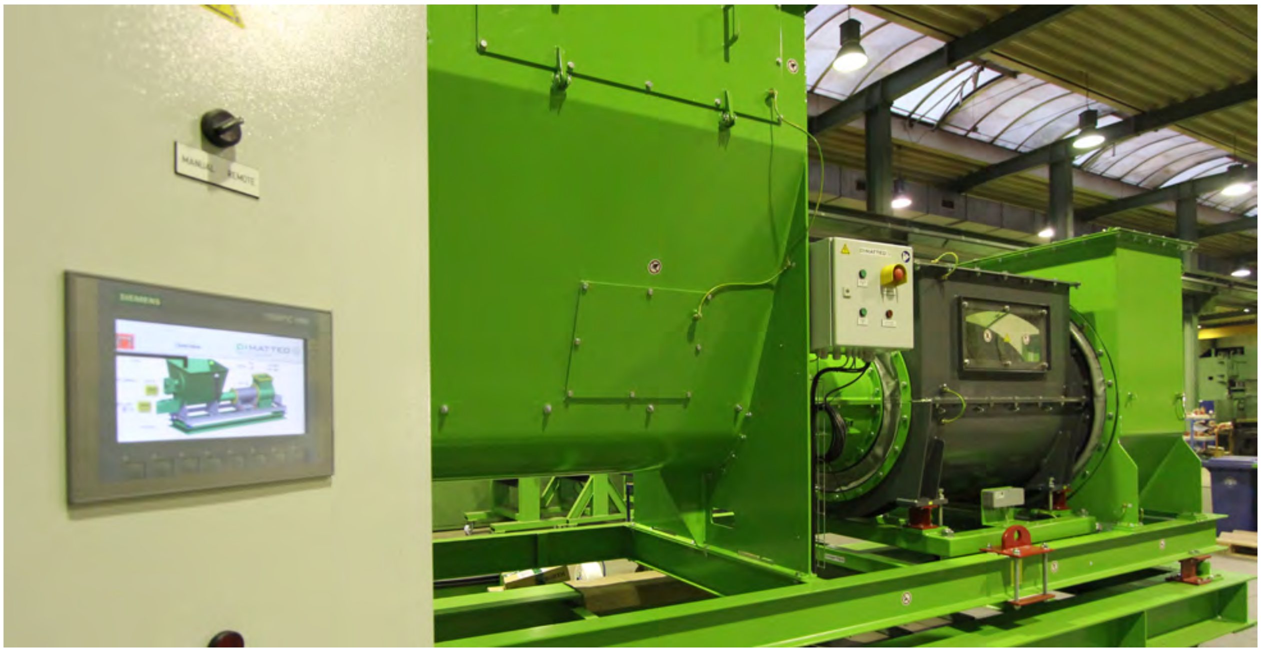


Figure 1- ODM-WeighTUBE® (back) and ODM-GravitAS control system (front)

In order to give a clear guideline which proportioning system or method is a preferable solution within different application scenarios, this article provides an introduction to a framework for the systematic classification and description of different approaches to dosing and metering of bulk materials, which was developed by DI MATTEO. With the integration of the classification system a corresponding taxonomy is proposed. For this reason, section 2 introduces a general classification framework for metering and dosing units. This classification is then used in section 3 to differentiate the typical range of products within the field of bulk material proportioning. One of the latest developments within the field of bulk material proportioning is the introduction of the award-winning ODM-WeighTUBE®, which is presented in section 4. Finally section 5 summarises the article and provides a conclusion to the topic.

2.General Classification of Bulk-Material Dosing Devices

The base for a classification of different dosing and proportioning devices for bulk materials is the former definition of the functional entities of those machines. For this it is reasonable to distinguish three main functional elements of typical dosing devices: (i). measuring, (ii). conveying and (iii). controlling as proposed in [5]. The combination of either any two or all three of these basic elements defines the specific character of the equipment, as shown in Figure 2.

Here, it is possible to name six different classes of machines as a general taxonomy for the proportioning of bulk materials. The exact definition and corresponding aspects are summarised within Table 2.

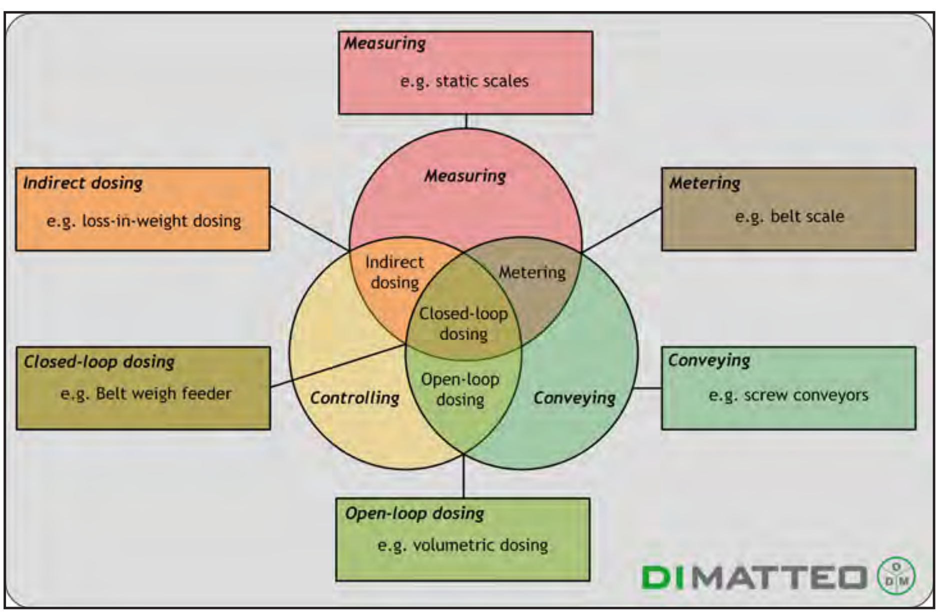


Figure 2- Classification of different dosing/metering/weighing devices based on three basic functional elements

Table 2 - Overview of different dosing/metering/weighing devices

Class of Machine	Measuring	Metering	Indirect dosing	Open-loop dosing	Closed-loop dosing
Description	The actual volume V or weight m of the material is measured and used to define the actual amount at .a given time	The material is conveyed with a certain conveying speed v and at the same time the actual massflow is $\dot{M}$ determined based on a measured weight .m	The actual volume V or weight m of the material is measured and used to define the actual amount at a given time and at the same time a separate conveying system is controlled in order to achieve a certain volume flow $\dot{V}$ or mass flow $\dot{M}$.	The actual conveying speed v is controlled based on a pre-defined calibrated relation in order achieve a certain volume flow . $\dot{V}$ or mass flow $\dot{M}$	The actual weight m or volume V and the actual conveying speed v is measured to calculate the actual mass flow or $\dot{M}$ volume flow $\dot{V}$. The actual conveying speed is continuously controlled in order to achieve a desired mass or volume flow.
Measured values	m [kg], V [m³]	v [m/s], m[kg]	v [m/s], m[kg]	-	v [m/s], m[kg], $\dot{V}$ [[m³/h], $\dot{M}$ [kg/h
Control variables	--		$\dot{V}$ [m³/h], M [[kg/h	v [m/s]	v [m/s] → $\dot{V}$ [m³/h], $\dot{M}$ [kg/h]
Type of operation	-	Continuous	Discontinuous	Continuous	
Type of dosing	--		Gravimetric	Gravimetric	
Example	Silo scale	Belt scale	Differential dosing setups (e.g. loss-in-(weight systems	Screw conveyor wit pre-defined calibrated relation between volume and screw speed	ODM-WeighTUBE®

All of these machines are justified within their specific field of application and there is no suitable piece of equipment which can meet all technological and economic requirements of every possible field of application. If for example a continuous flow of material is required by the process (e.g. supply of alternative fuels), there is no possibility to utilize an indirect dosing setup, such as a loss-in-weight system, even if other aspects indicate it.

Therefore DI MATTEO developed and offers products from all the mentioned categories and within the next section, some of the available products will be classified by using the aforementioned framework, in order to get a clear understanding of the physical realisation of the intrdocued categories.

3. Typical Proportioning Equipment

There is a great variety of available products in the field of bulk material dosing and proportioning and within this section some prominent examples are used to clarify the taxonomy as introduced in section 2. For this the six categories, as introduced in Table 2, are used to provide a classification of the product range from DI MATTEO.

3.1 Pure Measuring Devices – Silo Scales and Weighing Hoppers

Typical examples for pure measuring devices are weighing hoppers and silo scales, which are mainly used in order to determine the actual filling in terms of weight m [kg] and/or, for bulk material with constant density and humidity, also the volume V [m³]. The mass of the material is measured by means of a set of load cells, corresponding mechanical mounting modules for effective force transmission (see Figure 3) and a corresponding evaluation unit.

Figure 3- Typical load cell module for silo scales or weighing hoppers

A proper proportioning of the material within the silo or hopper is only possible, if the setup is complemented with a controllable discharge system (e.g. a screw discharge bottom – ODM-ScrewDOS). Such a setup would be an indirect dosing system, where the following section provides an example.

3.2 Indirect Dosing – Differential Dosing Setups

The indirect dosing setup consists typically of a silo scale or weighing hopper, which is equipped with a controllable discharge system, as shown in the general principle illustrated in Figure 4. Here a screw is used to discharge a hopper, which is placed on a set of load cells, which acquire the actual material weight m [kg], within the hopper. By using the loss-in-weight principle the actual mass flow $\dot{M}$ [kg/h] can be continuously calculated by taking into consideration the mass difference Δm [kg] within a defined time interval Δt [s] (time derivative of the material weight), according to the following relation:
By an adaption of the screw speed it is therefore possible to achieve a desired mass- or volume flow. However, the main drawback of this setup is the missing possibility to dose the material continuously, since the relation shown

$$\dot{M} = 3600 \cdot \frac{dm}{dt} \approx \frac{3600 \cdot \Delta m}{\Delta t} \qquad [\mathrm{kg/h}] \qquad \text{(I)}$$

above is of course only true, if there is no simultaneous material infeed to the hopper. This means, that the setup

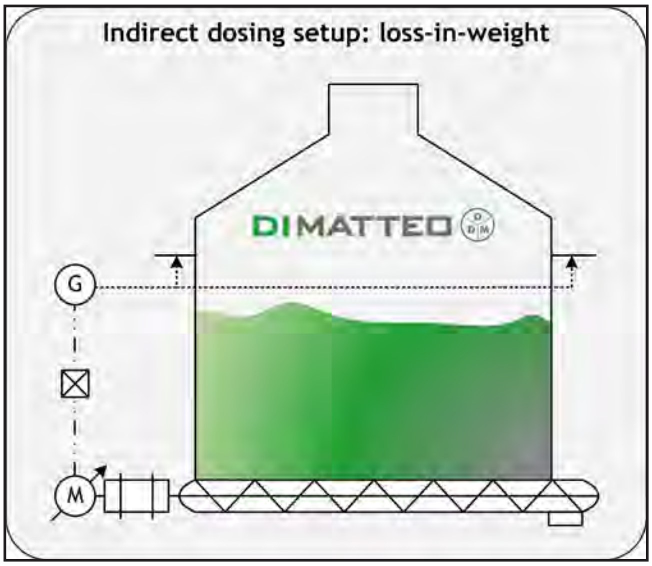


Figure 4- Setup of the indirect dosing architecture (here: loss-in-weight differential dosing)

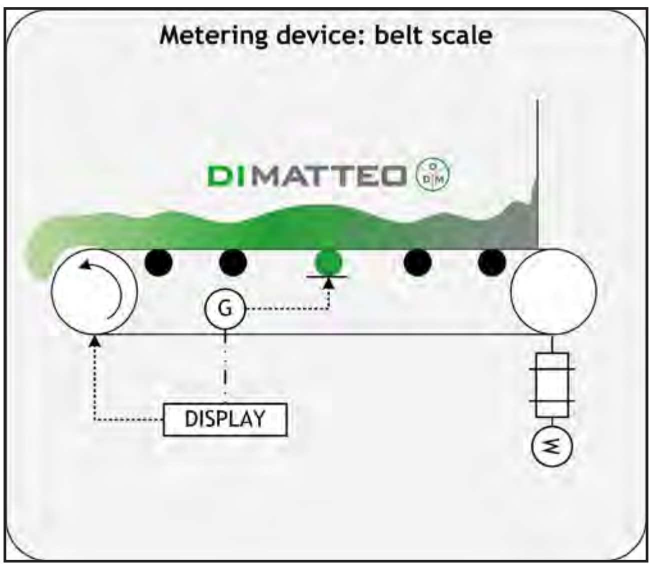


Figure 5- Example for a metering device (here: belt scale)

Figure 6 – ODM-ScrewMASTER Screw scale

is only suitable for batch-type dosing tasks, such as batch mixing or filling.

3.3 Metering – Belt scales and ODM-ScrewMASTER

The process of metering of mass flows consists of a standard conveying system (e.g. a belt or screw conveyor) and the determination of the actual flow by means of an integrated weighing system. As an example the typical belt scale is shown in Figure 5, where a belt conveyor transports material with a certain speed v [m/s] to a single weighing roller (marked in green), which determines the actual belt load m_{belt} [kg].

From the measured belt load m_{belt} it is possible to compute the actual mass per length unit (Δm/Δl [kg/m]), which can be used to determine the actual mass flow $\dot{M}$ [kg/h] as follows:

The standard metering device contains no control circuit at all, since it is only computing the actual mass flow but there is no feedback between this information and the actual speed of the conveyor. DI MATTEO offers such metering devices either as belts

$$\dot{M} = 3600 \cdot \frac{\Delta m}{\Delta l} \cdot v \qquad [kg/h] \qquad (II)$$

or as screw conveyors. An ODM-ScrewMASTER screw scale (as shown in Figure 6) has the advantage that the system is completely closed and dust-proof and represents therefore in many cases the preferable solution.

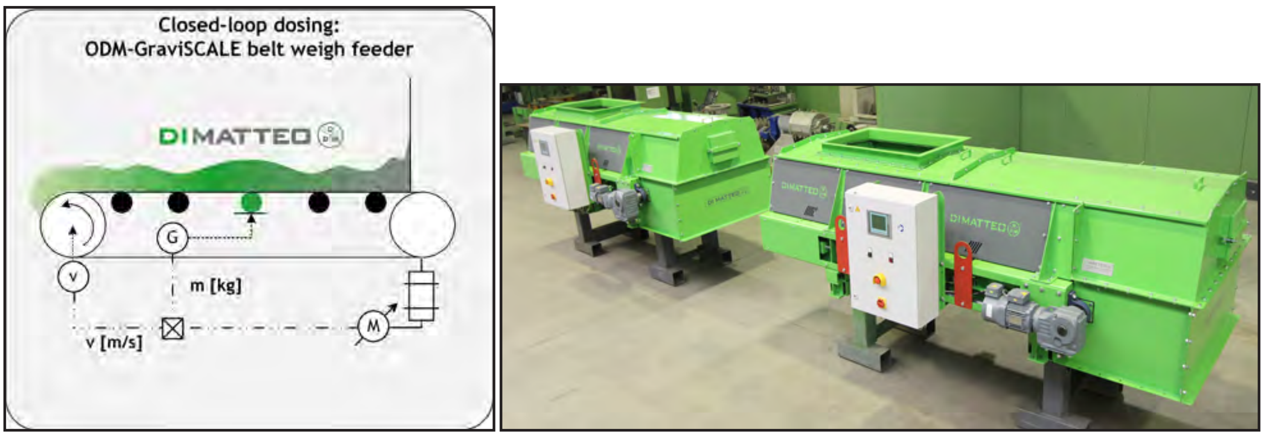
3.3 Open-loop dosing

Open-loop dosing is also often called volumetric dosing, since the main principle behind it is the operation of a certain conveyor with a certain pre-defined speed for each possible mass flow setpoint. Thus, the actual weighing of the real material weight is neglected and instead it is assumed, that for the generation of a constant mass flow $\dot{M}$ [kg/h] it is sufficient to generate a constant volume flow [m³/h]. This assumption is of course only valid, if it can be guaranteed that the bulk density ρ [kg/m³] of the conveyed material is constant. Since there is no information of the actual mass flow from a gravimetric measurement unit, it is necessary to define a calibration curve $\dot{V}$ or generalised mathematical relation in order to define the dependency between the actual speed of the conveyor v [m/s] and the mass flow. In most cases volumetric dosing is realised by a screw conveyor, since the usage of a through or tubular screw conveyor guarantees a quite stable volumetric feeding behaviour for different speeds if compared to e.g. a belt.

However, especially for materials with time-varying properties and volatile humidity or density, e.g. for the accurate dosing of alternative fuels, a closed loop dosing method is not applicable.

3.4 Closed-loop dosing – ODM-GraviSCALE and ODM-WeighTUBE®

The most sophisticated and accurate solution for the proportioning of bulk materials is closed-loop dosing, which is often also referred to as gravimetric dosing, since the actual mass flow $\dot{M}$ [kg/h] is determined by means of an integrated weighing unit.
The most prominent example for such a system is the ODM-GraviSCALE belt weigh feeder, as shown in Figure 7 – (b). The working principle for the determination of the actual massflow is similar to the one shown in Equation (II), which means that the actual conveying speed v [m/s], as measured e.g. by an incremental encoder, and the actual material load m [kg] are evaluated continuously. As illustrated in Figure 7 – (a), the closed-loop principle can be interpreted in such a way, that there is a direct feedback from the calculated mass flow to the variable speed drive unit. If there is a deviation between the actual mass flow and the desired setpoint, the actual conveying speed can be therefore continuously adapted. Thus, a high precision of the dosing operation is guaranteed and typically the maximum deviation from the setpoint lies below ±2%.



(a) (b)

Figure 7 – ODM-GraviSCALE belt weigh feeder – (a) methodology; (b) machine

However, the operation of belt weigh feeders in practical applications is characterised by two main aspects: First of all, it needs to be said that belts are by nature non-closed systems. This leads to non-negligible dust emissions and spillage of material, which affects as a logical consequence subsequently the weighing units and their accuracy. DI MATTEO designed the ODM-GraviSCALE in such a way to avoid those effects as much as possible, which is achieved by a smart casing, sealing and scraping concept.
On the other hand and as it was already stated above, all existing dosing methodologies are suffering immensely from possible time-variant material properties of the conveyed bulk. This leads in practical applications to a non-negligible drift in the dosing accuracy over time. Thus, belt weigh feeders need to be recalibrated on a regular basis (e.g. once a month) in order to guarantee a long-term stability of the feeding process. This re-calibration needs to be done manually by service technicians in a time-consuming process, during that the machine has to remain offline.

These two aspects led in the past to the development of a completely novel closed-loop dosing system: the tubular weigh feeder ODM-WeighTUBE®, which is described in detail within the next section.

4. ODM-WeighTUBE® - A Novel Gravimetric Closed-Loop Dosing Unit

The initial base for the development of the ODM-GravitAS control system was the introduction of the innovative ODM-WeighTUBE® platform in 2010. Even if the first installations of the novel dosing system were mainly focused on plants for problematic bulk material, such as residue derived fuels (RDF), shredded tires or polyethylene granulate material, actually roundabout one hundred units of the ODM-WeighTUBE® are successfully integrated around the world and have been also used for more conventional bulk materials, such as raw meal, fly ash, iron core or clinker. This can be interpreted as a great success, especially for a relatively conservative industrial branch, such as the cement industry. Figure 8 provides an overview of the ODM-WeighTUBE® RWS series, in the German production facility of DI MATTEO . Up to know, there are three different models of the WeighTUBE® available (RWS 500, RWS 400, RWS 250) depending on the type of bulk material and the intended dosing range.

Figure 8- ODM-WeighTUBE® RWS series

The general dosing principles is similar to the classical closed-loop scheme, as it was introduced for the ODM-GraviSCALE belt weigh feeder. The same idea is transferred to a screw conveyor, as shown in Figure 9. The WeighTUBE consists of a tubular screw conveyor, which is continuously discharging material from an intermediate buffer. The material is conveyed to the tube section, which is placed on a set of load cells and decoupled from the main frame of the machine by flexible connections. Therefore it is possible to measure the actual material weight within the tube (tube weight) m_{tube} [kg]. Furthermore, the actual conveying speed of the screw v_{screw} [m/s] is continuously acquired. Similar to the principle shown in Figure 7 – (a), both physical values are processed in order to calculate the actual mass flow $\dot{M}_{act}$ [kg/h]. By taken into consideration the desired mass flow (setpoint) it is possible to determine the actual deviation e [kg/h], which is fed to the continuous dosing controller (CDC), which calculates the necessary adaption of the screw speed in order to minimize the deviation under all circumstances and at any given time. All software elements are implemented within the ODM-GravitAS control system, which was developed by DI MATTEO as a unified platform for all weighing and dosing applications (see [6]).

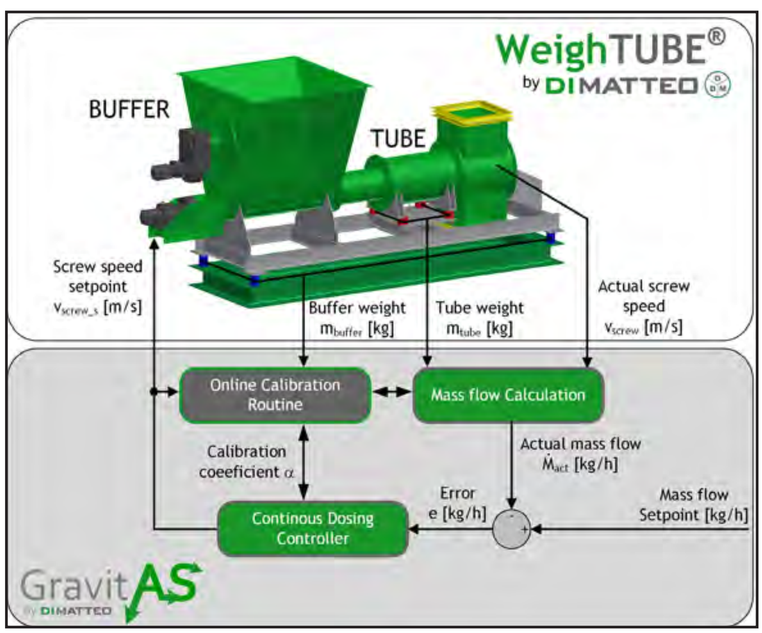


Figure 9- ODM-WeighTUBE® closed-loop control circuit

Furthermore, the ODM-GravitAS control system implements an automatic calibration routine, which provides the possibility to estimate properties of the dosed bulk material and automatically adapt the controller parameters in such a way that the dosing accuracy remains stable over time. The actual process operation is not influenced by the execution of the automatic calibration routine, so that the available machine time can be increased.

During the automatic calibration routine the intermediate buffer hopper of the ODM-WeighTUBE is filled to a certain maximum in a first stage of operation. Within the second phase the buffer hopper is emptied by normal dosing operation (and parallel stopped feed of material to the buffer) up to a predefined minimum buffer weight. From the resulting difference in mass (Δm) and the corresponding expired time (Δt), the actual control parameters of the continuous dosing controller are automatically adapted. To avoid possible undesired influences, all controller parameters are checked for plausibility based on a probabilistic analysis of former calibration cycles, before they become active in the system. A typical calibration process, with its three phases, is shown in the following figure, where the actual buffer weight mplant [kg] is visualised over time.

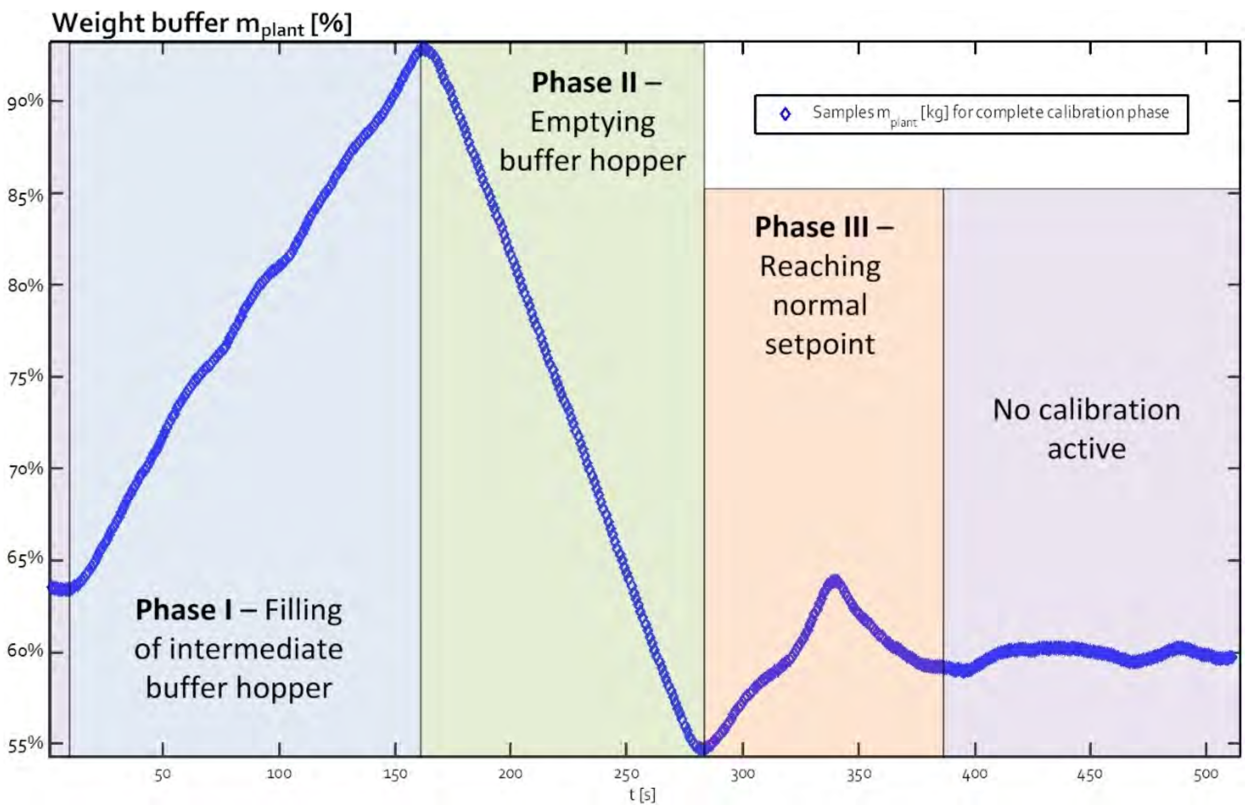


Figure 10- Three phases of a calibration routine

The decreasing buffer weight in phase II of the calibration process follows an almost exact linear pattern, which can be interpreted as a manifestation of the highly constant material throughput of the device. A possible deviation between the actual and the desired mass flow during this phase is evaluated for the probabilistic adaption of the controller parameter.

The possibility for a continuous on-the-fly auto-tuning of the controller depending on the given material properties is a very important element for long-time stability and accuracy of the gravimetric dosing. In particular, if the decreasing quality of alternative fuels derived from industrial waste (see [6]) is taken into account. By the combination of the ODM-WeighTUBE® platform with the GravitAS control system a high dosing precision of <±1% related to the nominal throughput can be guaranteed.

Summary and Conclusion

This article introduced a framework for the systematic classification of dosing and metering equipment for cement plants and relative industries. The defined taxonomy allows a better understanding of the exact nature of a certain type of equipment and can be used as a guideline during the design and implementation of system setups.

Each class of system was defined in detail by using the complete variety of dosing and weighing equipment as offered by DI MATTEO, from static silo scales and weighing hoppers to the latest developments in closed-loop high-precision dosing (e.g. ODM-GraviSCALE belt weigh feeder).
Another important aspect for the selection of adequate dosing equipment is the typical "status-quo decision-making trap" as described in [7]. It mainly states, that the logical consequence of most buying decisions in larger organisations is just the preservation of the current technological state. This is especially observable in relative conservative industries, such as cement manufacturing, since in most cases those systems are unintentionally preferred, that are already known. This has severe consequences on the competitive situation of many organisations, because it might happen that technological developments are adopted too late or even completely neglected.

This article introduced the ODM-WeighTUBE® as the latest development in gravimetric long-term stable high accurate dosing of bulk materials, which has proven its capability to solve many problems and drawbacks of classical proportioning equipment in numerous different application fields. This can be considered to be a possibility to break the wall of the status-quo and guarantee long-term reliability and fast return-on-investment.

References

[1] Aufderheide, D., Di Matteo, L.: Best Practice Approaches for Co-Processing of Alternative Fuels in the Cement Industry. In Cement International 1 (2017), pp. 26- 33, Verlag Bau und Technik, Erkrath, Germany – ISSN 1610- 6199

[2] Di Matteo, L., Aufderheide, D.: Classifying Alternative Fuels Handling Systems. In World Cement 3 (2016), pp. 23- 29, Palladian Publishing, Farnham, UK – ISSN 0263- 6050

[3] Aufderheide, D., Di Matteo, L.: Dynamic Dosing. In World Cement 12 (2014), pp. 63- 68, Palladian Publications, Farnham - ISSN 0263- 6050

[4] Aufderheide, D., Di Matteo, L.: Full Modular Control System for Gravimetric Dosing Applications. In ZKG 11 (2014), pp. 44- 49, Bauverlag, Gütersloh - ISSN 0949- 0205

[5] Aufderheide, D., Di Matteo, L.: Getting the right Dose. In International Cement Review (ICR) 3 (2017), pp. 90- 94, Tradeship Publications Ltd, Dorking, UK – ISSN 0959- 6038

[6] Aufderheide, D., Di Matteo, L.: ODM-GravitAS for DI MATTEO WeighTUBE feeders – A Full Modular Control System for Gravimetric Dosing Applications. In Global Cement Magazine 2 (2015), Pro Global Media Ltd., Epsom - ISSN 1473- 7940

[7] Emiliani, M.L.: Executive Decision-Making Traps and B2B online reverse auctions. In Supply Chain Managament: An International Journal 1 (11) (2006), pp. 6 - 9