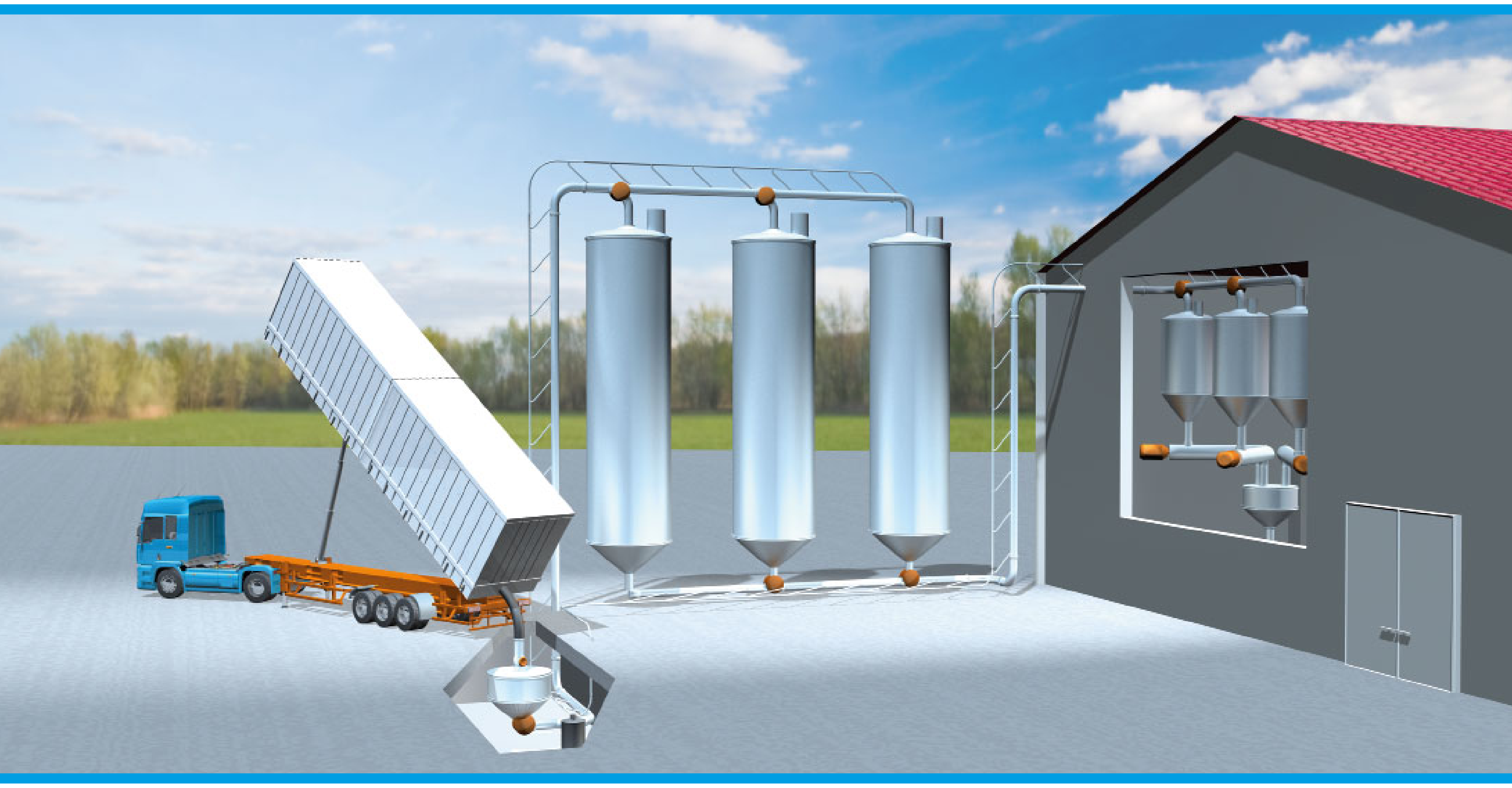
Handling of carbon black

Technical Information TI 1451



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1 Introduction

1.1 What is carbon black?

“Carbon black” is the most frequently used term for industrially produced carbon, even in countries with other native tongues than english. Orion Engineered Carbons employs four different processes to produce carbon blacks. While the globally used furnace black process is currently the most important, the company also relies on the Degussa gas black process and as well on the thermal black process. These can be accurately controlled and allow targeted, reproducible, and consistent production of a variety of different grades of carbon black, that are precisely defined by specifications and meet a wide range of requirements in various fields of application. Well over 100 grades of carbon black with special property profiles are currently available.

Table 1

Terms for carbon black

	Undefined	Defined
German	Ruß	Ruß
English	Soot	Carbon black
French	Suie	Noir de Carbone
Italian	Fuliggine	Nero di Carbonio
Spanish	Hollin	Negro de Humo

Table 2 lists the carbon black grades produced by Orion Engineered Carbons along with some of their physical and chemical handling data. This information is for reference only; please refer to the current specifications when working with individual carbon blacks.

Further information on this subject is available in the Orion Engineered Carbons brochure “What is carbon black?”.

Table 2

Some characteristic carbon black data for Orion Engineered Carbons

No.	Carbon black grade	Nitrogen surface area BET [m²/g]	OAN [ml/100 g]	Bulk density, powders [g/l]	Bulk density, granules [g/l]
1	PRINTEX® U	92	115	110	380
2	PRINTEX® V	92	115	150	n. a.
3	PRINTEX® 140 U	90	115	120	n. a.
4	PRINTEX® 140 V	90	115	160	n. a.
5	PRINTEX® 95	240	52	n. a.	470
6	PRINTEX® 90	350	98	140	360
7	PRINTEX® 85	200	54	220	480
8	PRINTEX® 80	225	105	180	360
9	PRINTEX® 75	145	53	220	490
10	PRINTEX® 55	100	47	250	510
11	PRINTEX® 45	90	54	220	540
12	PRINTEX® alpha-A	105	100	n. a.	410
13	PRINTEX® P	120	102	n. a.	410
14	PRINTEX® 60	115	118	200	400
15	PRINTEX® 60-A	115	102	n. a.	400
16	PRINTEX® L6	270	126	210	320
17	PRINTEX® L	150	120	220	330
18	PRINTEX® 300	80	68	260	460
19	PRINTEX® 30	80	108	220	410
20	PRINTEX® 3	80	128	190	n. a.
21	PRINTEX® 35	60	42	360	630
22	PRINTEX® 25	48	45	380	610
23	PRINTEX® 200	45	45	n. a.	610
24	PRINTEX® A	43	130	190	420
25	PRINTEX® G	35	104	220	470
26	PRINTEX® 12	25	65	n. a.	530
27	PRINTEX® XE2-B	1000	420	n. a.	140
28	PRINTEX® HV	125	115	n. a.	370
29	PRINTEX® F 85	200	54	n. a.	480
30	PRINTEX® F 80	225	105	180	360
31	PRINTEX® F alpha	105	100	n. a.	410
32	PRINTEX® F P	120	102	n. a.	410
33	PRINTEX® L6 SQ	270	126	n. a.	320
34	PRINTEX® alpha SQ	105	100	n. a.	410
35	PRINTEX® 260	107	56	–	464
36	PRINTEX® 27	46	45	224	550

No.	Carbon black grade	Nitrogen surface area BET [m²/g]	OAN [ml/100 g]	Bulk density, powders [g/l]	Bulk density, granules [g/l]
37	PRINTEX® 310	75	102	–	368
38	PRINTEX® 314	71	120	–	336
39	AROSPERSE 11	120	116	150	336
40	AROSPERSE 15	9	40	n.a.	480
41	AROSPERSE 3	75	102	n.a.	368
42	AROSPERSE 5	39	120	n.a.	376
43	AROSPERSE 5–289	39	90	n.a.	432
44	AROSPERSE 7	30	80	n.a.	448
45	AROSPERSE 7–256	25	65	n.a.	496
46	AROSPERSE 138	120	95	n.a.	355
47	AROSPERSE 26	107	61	n.a.	465
48	AROSPERSE 309	81	102	n.a.	350
49	AROSPERSE F138	120	95	n.a.	355
50	COLOUR BLACK FW 200	550	160	130	380
51	COLOUR BLACK FW 285	350	175	120	n.a.
52	COLOUR BLACK FW 2	350	155	130	380
53	COLOUR BLACK FW 1	320	150	130	350
54	COLOUR BLACK FW 182	560	150	110	n.a.
54	COLOUR BLACK FW 18	260	140	70	360
55	COLOUR BLACK S 160	180	128	170	380
56	COLOUR BLACK S 170	200	135	170	n.a.
57	COLOUR BLACK FW 171	650	106	180	n.a.
58	HIBLACK® 900L	270	60	220	n.a.
59	HIBLACK® 890	270	95	160	n.a.
60	HIBLACK® 600L	235	72	210	n.a.
61	HIBLACK® 600LB	268	68	n.a.	450
62	HIBLACK® 50L	188	55	210	n.a.
63	HIBLACK® 40B1	153	130	n.a.	305
64	HIBLACK® 40B2	125	150	n.a.	280
65	HIBLACK® 420B	80	153	n.a.	300
66	HIBLACK® 40L	135	55	220	n.a.
67	HIBLACK® 45LB	142	52	n.a.	420
68	HIBLACK® 40	138	100	170	n.a.
69	HIBLACK® 30L	105	55	220	n.a.
70	HIBLACK® 30	123	110	170	n.a.
71	HIBLACK® 20L	86	55	215	n.a.
72	HIBLACK® 20	90	105	180	n.a.
73	HIBLACK® 10	70	97	180	n.a.

No.	Carbon black grade	Nitrogen surface area BET [m²/g]	OAN [ml/100 g]	Bulk density, powders [g/l]	Bulk density, granules [g/l]
76	HIBLACK® 5 L	68	73	215	n. a.
77	HIBLACK® 150B	42	122	n. a.	350
78	HIBLACK® 160B	36	85	n. a.	400
79	HIBLACK® 170	23	80	230	n. a.
80	LAMP BLACK 101	20	117	180	410
81	NEROX® 305	90	58	190	n. a.
82	NEROX® 505	103	58	210	n. a.
83	NEROX® 605	125	56	210	n. a.
84	NEROX® 500	114	110	150	n. a.
85	NEROX® 600	130	100	160	n. a.
86	NEROX® 1000	36	101	170	n. a.
87	NEROX® 2500	51	54	250	n. a.
88	NEROX® 3500	64	50	250	n. a.
89	NIPex® 150	175	120	170	n. a.
90	NIPex® 160 IQ	180	128	170	n. a.
91	NIPex® 170 IQ	200	135	170	n. a.
92	NIPex® 180 IQ	260	140	70	360
93	NIPex® 35	60	42	360	630
94	NIPex® 60	115	118	200	400
95	NIPex® 70	270	126	210	n. a.
96	NIPex® 90	350	98	140	n. a.
97	PANTHER® 100	25	66	147	235
98	PANTHER® 205	33	72	–	130
99	SPECIAL BLACK 6	300	170	180	430
100	SPECIAL BLACK 5	240	130	170	430
101	SPECIAL BLACK 4	180	115	170	430
102	SPECIAL BLACK 4 A	180	95	n. a.	380
103	SPECIAL BLACK 550	100	47	310	550
104	SPECIAL BLACK 350	65	45	450	n. a.
105	SPECIAL BLACK 250	48	49	450	n. a.
106	SPECIAL BLACK 100	30	100	240	n. a.

No.	Carbon black grade	Nitrogen surface area BET [m²/g]	OAN [ml/100 g]	Bulk density, powders [g/l]	Bulk density, granules [g/l]
107	CORAX® N 115	124	113	n. a.	345
108	CORAX® N 121	114	132	n. a.	320
109	CORAX® N 134	131	127	n. a.	320
110	CORAX® N 220	106	114	n. a.	350
111	CORAX® N 234	113	125	n. a.	325
112	CORAX® N 326	77	72	n. a.	455
113	CORAX® N 330	76	102	n. a.	370
114	CORAX® N 339	88	120	n. a.	340
115	CORAX® N 347	83	124	n. a.	330
116	CORAX® N 351	70	120	n. a.	345
117	CORAX® N 375	90	114	n. a.	345
118	CORAX® N 539	38	111	n. a.	385
119	CORAX® N 550	39	121	n. a.	365
120	CORAX® N 650	35	122	n. a.	360
121	CORAX® N 660	34	90	n. a.	440
122	CORAX® N 683	34	133	n. a.	350
123	CORAX® N 762	28	65	n. a.	490
124	CORAX® N 772	30	65	n. a.	530
125	CORAX® N 774	29	72	n. a.	495
126	CORAX® HP 160	153	130	n. a.	300
127	DUREX® 0	117	150	150	375
128	ECORAX®1670	92	140	n. a.	310
129	ECORAX® 1720	115	135	n. a.	320
130	ECORAX® 1990	130	108	n. a.	370
131	ECORAX® S 204	19	138	n. a.	345
132	ECORAX® S 206	19	73	n. a.	520
133	CK3	75	104	n. a.	380
134	PUREX® LS 18	19	73	n. a.	520
135	PUREX® HS 20	19	138	n. a.	345
136	PUREX® HS 22	20	102	n. a.	430
137	PUREX® HS 25	28	123	n. a.	375
138	PUREX® LS 35	30	51	n. a.	610
139	PUREX® HS 40	38	111	n. a.	385
140	PUREX® HS 45	39	121	n. a.	365
141	PUREX® HS 45-RP	39	121	n. a.	365
142	PUREX® HS 55	48	133	n. a.	335
143	Thermal Black N 990	10	38	n. a.	640

The physico-chemical data in this table are current guide values valid at the time of press release

1.2 Production methods

Carbon Black is obtained by incomplete combustion or thermal cracking of hydrocarbon-rich raw materials. Orion Engineered Carbons uses various processes to produce carbon blacks, the most important of which include

- the furnace black process,
- the Degussa gas black process, and
- the LAMP BLACK process.

Among these, the furnace black process is by far the most important in terms of output. It involves spraying liquid feedstock into a flame of hot air and natural gas, where it undergoes an incomplete thermal oxidation at high temperatures. The carbon black produced from the gases is then separated with filter systems. The Degussa gas black Process consists of streaming a carrier gas containing hydrogen over hot tar oil, with incomplete combustion of the vaporized oil in a large number of small flames. These flames are directed toward water-cooled rollers. A portion of the carbon black generated is deposited on the rollers while the rest enters the filter system. In the next stage the two carbon black streams are combined. At the core of the LAMP BLACK Process is a bath containing liquid feedstock that sits under a refractory extraction hood. The incomplete combustion can be controlled by varying the gap between bath and hood.

The production methods for carbon black are described in detail in the brochure entitled "What is carbon black?". The various manufacturing processes produce a range of carbon black grades, that differ in primary particle size, structure, surface area, and surface groups. Among other factors, these parameters affect jetness, tinting strength, hue, rheology, dispersibility, oil requirements, and electrical conductivity.

1.3 What handling covers

In this publication, "handling" refers to all measures or process steps for shipping carbon blacks from the production site to the point of direct customer use. Handling therefore covers the choice of packaging and shipment to the user, along with internal storage and metering within the user's plant. **Table 3** shows the process steps for the handling of carbon blacks from the producer to the user. It is particularly important for these steps to be dust-free, because even a few particles of carbon black can cause extensive staining. Moreover, the dust content of air in the workplace is subject to legal limits, which can only be met by proper product handling. More details on product safety are described in section 7.

Table 3

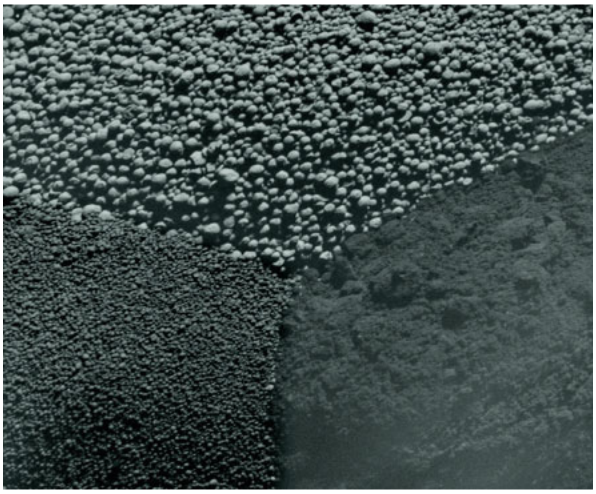
Packaging	Transportation to user	Within the user's production facility		
	Step A	Storage, step B	Conveying, step C	Metering, step D
Bulk material	Road or rail silo or container	Storage silo	Pneumatic, by pumping, or mechanical	Continuous: mechanical
Semi-bulk materials	Small container	Small container, day silo		Discontinuous: mechanical, pneumatic
Bags	Pallets, lose bags	Pallets, day (small) silo		

Overview of possible process steps in the handling of carbon black

2 Delivery forms of carbon black

Regardless of the production process, carbon blacks leave the reactor in pulverized form. The first process for granulating carbon blacks was developed in 1934 and made it simpler to handle the product by significantly reducing the amount of dust. Today, two processes for granulating carbon blacks exist. The original wet granulation process uses water and, if needed, a binder to produce the granules. The resulting wet granulated carbon blacks are commonly used in the rubber industry. These granules tend to be more stable than those produced by the dry granulation process, in which carbon black is granulated without any additives. The easily dispersible, dry granulated carbon blacks are used mainly as a pigment in the printing-ink and plastics industries. Despite the simpler handling of granulated carbon blacks, there are still a few application areas, such as automotive coatings, where carbon blacks must be used in pulverized form to achieve the required application fineness. The differences between the individual delivery forms are shown in **figure 1**.

Figure 1



Delivery forms of carbon black: wet granulated (above), dry granulated (above left), powdered (above right)

Although carbon black granules, and particularly the wet granulated variety, are considered highly stable in processing, they must be handled and transported with great care. Granulated carbon black grades are classified as fragile for material handling purposes and care must be taken during handling to prevent granule damage, which leads to a drastic deterioration of the handling properties of the carbon blacks. Section 4 of this publication provides further details on possible damage to the granules in transport. The available packaging formats are also adapted to the bulk and handling properties of the individual delivery forms. Depending on the carbon black grade, packaging options include bags, semi-bulk packaging, and silo (bulk) shipping for granulated carbon blacks.

2.1 Shipping in bags

In general, carbon blacks are shipped in multi-layer paper valve bags that are specifically designed to meet the transport and storage requirements of the product in question. These bags vary in dimensions, paper quality, and number of layers, and may also have linings or interlayers that protect against moisture. Bagged material is usually shipped on pallets, with pallet dimensions matching the dimensions of the bag and the means of transport. Depending on the requirements, the pallets may be shrink-wrapped (see **figure 2**) or simply wrapped up, or the individual bags may be placed next to one another to prevent slipping. These measures guarantee secure transport, while full shrink-wrapping also provides a certain degree of weather protection.

Figure 2

Shrink-wrapped pallet for shipping of bags

2.2 Semi-bulk shipping

2.2.1 Flexible intermediate bulk containers (FIBCs)

Semi-bulk packaging of carbon black relies on FIBCs (flexible intermediate bulk containers) as shown in **figure 3**. Also known as big bags or super sacks, these flexible small containers are suitable for capacities ranging from 1 to 2.4 m^3. Standard FIBCs hold about 2 m^3, depending on the grade of carbon black. Other sizes are offered as special packaging. FIBCs made of polypropylene fabric with specially sealed seams have proven particularly useful. Depending on the product, these FIBCs may also have certain inserts that increase stability.

FIBCs have a central filling spout on top and a central discharge spout in the base. Four lifting loops sewn into the top corners suspend the container while it is being emptied. When the container is suspended, the discharge spout on the bottom hangs freely and allows the bag to be emptied. The exact dimensions of FIBCs used are available on request. FIBCs can be shrink-wrapped for shipping in the same manner as palleted bags.

Figure 3

Example of an FIBC (flexible intermediate bulk container)

2.2.2 Intermediate bulk containers (IBCs)

Intermediate bulk containers (IBCs) are small rigid containers with filling volumes in the mid-range between bags and bulk containers. These small containers can be used for granulated carbon blacks if there is no option to retroactively install a carbon black bunker or silo system for internal reasons or financial considerations. The small containers recommended for transport of carbon black are made of rustproof materials, have a useable volume of up to 2.5 m^3, and are equipped with filling and discharge spouts. Depending on the bulk density of the carbon black grade, each container holds up to 900 kg of granulated carbon black. IBCs are increasingly being replaced by the FIBCs described in section 2.2.1 because capital and transport costs (for empty containers) are very high.

2.3 Bulk shipping

Orion Engineered Carbons offers bulk shipping as a cost-efficient alternative for granulated carbon blacks. Depending on the quantity shipped, distance of transport, and space available at the purchaser's premises, this form of shipping is optimal for packaging and transport for economic and ecological reasons. Granulated carbon blacks can be purchased in single-compartment vehicles (see **figure 4**) as well as in double-compartment vehicles with volumes ranging from 60 to 90 m^3. For individual carbon black grades, bulk shipping in standard sea freight containers (bag-in-box system) is available in addition to silo vehicles. A suitable storage silo must be set up at the customer site to accept the delivery of bulk shipments.

Figure 4

Single-compartment silo truck for delivery of carbon black

The main advantages of silo delivery are:

- Low-dust formation (in compliance with dust and emission limits)
- Movement of large quantities with minimal manpower requirements
- Reduced packaging costs
- No disposal or return of packaging material and pallets
- No negative impact on product properties during transport
- Low floor space and warehouse requirements for storage
- Favorable conditions for further automatic processing

3 Discharge process

Regardless of the delivered carbon black type, care needs to be taken to generate as little dust as possible in the emptying process to avoid pollution. Suitable processes have to be in place for all procedures, from emptying bags to silo vehicle discharge.

3.1 Bag emptying

3.1.1 Manual emptying

Simple devices, that allow for virtually dust-free emptying of bags can easily be constructed by workshops at the customer site. A particularly simple version consists of an extraction hood that is attached to a funnel-shaped base and connected to a suitable suction device. The base contains a bar grate, where the bag is placed and split into two halves with a blade. Before emptying the two halves, the extraction hood is closed with a flexible dust skirt to prevent the escape of dust. This method allows for emptying up to 20 bags per hour. The emptied bag halves are rolled up directly within the hood and are conveyed into an attached waste bag through a lateral opening. The base of the emptying device leads to a collecting hopper, from where the carbon black can be transported directly to the conveying device or to an intermediate storage or day-use silo. Due to its simple structure and dust seal, this bag-emptying mechanism is only suitable for granulated carbon Blacks. Another manual method for bag emptying is shown in **figure 5**. In this case, the bag is placed on spikes attached at the top, cut open at the rear, and then emptied by closing the top. The empty bag exits to the left through an outlet into a pouch made of PE film. A filter attached to the emptying device ensures that all dust generated during the process remains in the system. This bag-emptying unit is therefore suitable for both granulated and powder carbon blacks. As a general rule, all opening, emptying, rolling, or folding up of bags need to be done within an enclosed space and with suction.

3.1.2 Semi-automatic emptying

Many versions of semi-automatic bag-emptying machines are available on the market. They differ in functional principle and use a wide range of automation mechanisms. The bag-emptying machine shown in **figure 6** is an example of an almost fully automated model. Bags are cut open, emptied, and compacted in automated steps, with bag loading as the only manual task. The bag is placed on a platform inside the machine. The emptying process is then initiated at the touch of two buttons (two-hand operation). The door of the machine closes and the bag is cut open by a rotating blade mounted on a pivot arm. The split platform then tips up, so that the bag is punctured by spikes and subjected to fluidization air. After emptying, the spikes are withdrawn and the bag is ejected and conveyed to a bag compactor.

Figure 5

Manual bag-emptying unit

Figure 6

Semi-automatic bag-emptying unit

Bag-emptying machines with a lesser degree of automation are equally suitable for use with carbon blacks. However, as a general rule, any type of emptying equipment must feature an automatic self-cleaning filter, with the filter area adjusted to the air flow and product properties. As described above for manual bag emptying, the first step of bag disposal must be integrated into the machine. Regardless of whether the bag is then manually folded or conveyed to an empty-bag compactor. This step must always occur within the machine (in the suction zone) because of the considerable dust this process may generate.

3.1.3 Fully automatic emptying

As the above description of semi-automatic equipment shows, a distinction between semi-automatic and fully automatic bag-emptying machines is not always apparent. This section therefore discusses the equipment typically used for very large numbers of bags. Such machines are generally equipped with a de-palleting station, bag separation system, and belt conveyors. The only work step is to position the entire pallet on a specially designed platform by means of a forklift truck; all subsequent steps are fully automated. After feeding into the machine, the bag passes along a number of rotating blades, that cut it open in longitudinal direction. The open bag then passes into a rotating drum for emptying. The product drops into a discharge hopper, from which it is immediately removed. The empty bags are moved through the drum via a discharge chute to an empty-bag compactor or baler. This type of equipment is only suitable for high consumption.

Figure 7

Mechanical agitation of an FIBC emptying device

3.1.4 Emptying of FIBCs

The FIBCs described in section 2.2.1 have a centrally positioned outlet spout on their bottom. To empty the bag, the spout is suspended above a suitable receptacle to release the material by force of gravity. Some products require mechanical agitation of the FIBC (see **figure 7**) to prevent the possible formation of bridges and ensure speedy and complete emptying of the FIBC. In particular, such mechanical agitation is required for all powder carbon blacks supplied in FIBCs. Double-ring emptying systems with a lowering lock ring (see **figure 8**) are the current state of the art for emptying FIBCs by gravity. Such systems allow for virtually dust-free emptying of FIBCs and consist of a receptacle with an internal tube. The closed discharge spout of the FIBC is slipped over this tube and lowering the lock ring clamps the discharge spout of the FIBC between the inner and outer tube of the receptacle, establishing a dust-proof connection between the FIBC and the emptying system. After the discharge spout is opened, it is stretched out by raising the FIBC, which can then be emptied. Emptying systems of this type are also optionally available with mechanical agitation. If the entire emptying station is weighed, metering is possible directly from the FIBC. Before the emptied FIBC is removed for disposal, it must be folded to a convenient size. It is important to minimize the associated dust with the use of appropriate equipment.

Figure 8

Connecting system for dust-free emptying of FIBCs

3.1.5 Emptying of IBCs

Small containers can be emptied by placing them on a day-use bin or appropriate receptacle with a suitable device. Opening the discharge valve empties the IBC by gravity, but discharge aids such as vibrating systems are recommended. Provided that appropriate discharge aids are used, IBCs are particularly suitable for granulated carbon blacks.

3.1.6 Unloading silo trucks

The emptying of silo vehicles presumes the availability of a storage silo at the customer site. Information on size and design is given in section 5.2. Silo vehicles can be emptied with pneumatic or gravity systems; transportation to the storage silo generally takes place with pneumatic or mechanical systems. Gravity bottom dump stations are used to empty silo vehicles, with subsequent transfer of the carbon black to a mechanical or pneumatic conveying system. Typically, single consumers use multiple grades of carbon black with a wide range of different bulk densities; speed-controlled transfer screws or locks are therefore recommended to avoid exceeding the maximum load limits of the emptying and conveying system. Again, air flow control is beneficial for smooth operation.

4 Conveying carbon clack

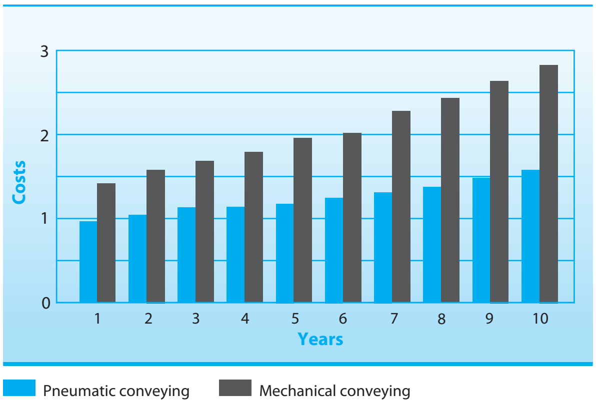
4.1 Pneumatic conveying

The descriptions in this section are intended for general information only. For investments, we recommend drawing on the experience of appropriate suppliers. Our handling technology department will be happy to advise you.

Pneumatic conveying generally has the following advantages over mechanical systems:

- Space-saving and flexible installation options, even if retrofitted
- Low overall costs (see **figure 9**)
- Residue-free discharge from pipelines with after-blowing; this is important, e.g., for product changes
- Dust-free working without environmental impact
- Few mechanically moving parts
- Low noise pollution if the conveying air system is correctly installed

Figure 9



Comparison of total costs for pneumatic and mechanical conveying

Ultimately, mechanical conveying represents the gentlest form of transportation for carbon blacks, and especially granulated carbon blacks. However, such systems have become the exception due to the above-mentioned advantages of pneumatic conveying. The most important exception is found in carbon black production facilities, where damage to granules over long conveying distances must be avoided as much as possible (see also section 4.4).

There are several types of pneumatic conveing systems. **table 4** offers an overview of the different methods. The data are based on the relevant technical literature and do not represent an opinion held by Orion Engineered Carbons.

Table 4

Loading of solid	Low load	Medium load	High load
Air flow rate [m/s]	20 – 40	10 – 20	2 – 10
Solid flow rate (relative to air flow rate) [%]	85 – 95	80 – 90	50
Load ratio [kg product/kg air]	2 – 3	5 – 10	> 20
Suction or pressure operation	Suction and pressure operation	Pressure operation	Pressure operation
Pressure range [bar]	– 0.5 – +0.5	0.5 – 1.0	1.0 – 6.0

Comparison of pneumatic conveying methods (data derived from technical literature)

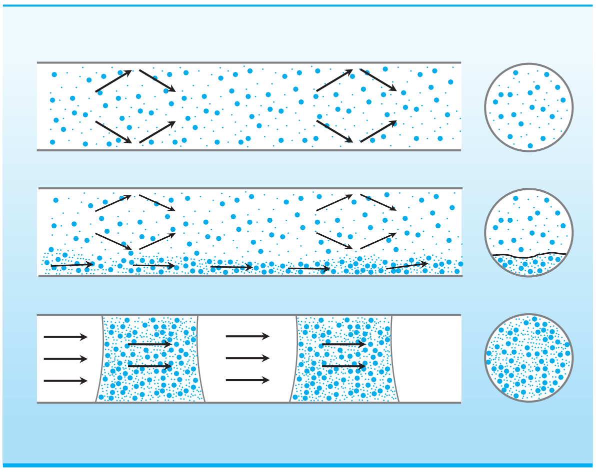
Distinction based on the loading of the material to be shipped:

- **Low loading** for entrained flow and dilute phase conveying works relies on an air speed of about 20 – 40 m/s. This type of pneumatic conveying is suitable for almost all bulk products. A load ratio of 5 kg/kg air is usually not exceeded. Both suction and pressure conveying methods are used.
- **Medium loading** works with air speeds of about 10 – 20 m/s. This type of pneumatic conveying results in intentional deposits in the pipeline, which are repeatedly dispersed. Therefore, this type of conveying is also known as strand conveying. The load ratios range from approximately 5 to 10 kg/kg air.
- **High loading** for dense phase conveying of granulated (and powder) bulk solids is characterized by load ratios above 20 kg/kg air. Designed for slow conveying, such systems work at 2 – 10 m/s. **Figure 10** shows the principles of the various options in schematic form.

As mentioned above, the distinctions between the methods are not always clear, as shown in the state diagram for pneumatic conveying (**figure 11**).

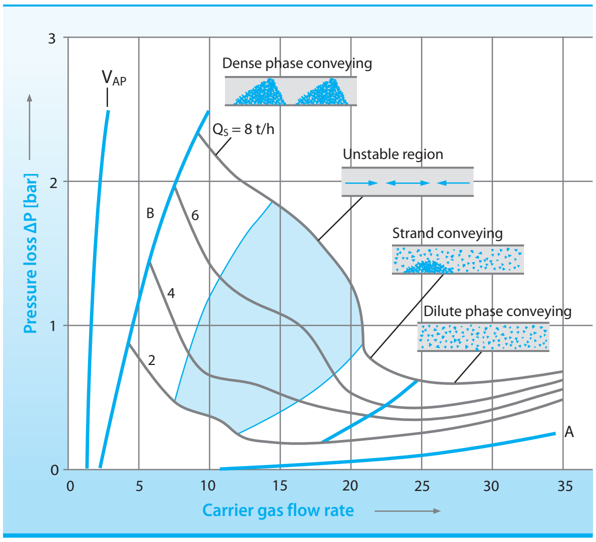
All conveying states of a pneumatic conveying system can be displayed between two boundary lines in the state diagram. At high carrier gas speeds and simultaneously decreasing mass flow rates, boundary line A describes the pressure loss of the air stream in an empty conveyor line. Boundary line B describes the state of a line that is becoming blocked with decreasing carrier gas speed. The mass flow rate QS underneath and to the left of these boundary lines is 0 mt/h. To the left of boundary line B, conveying is theoretically possible but is not stable and does not occur at the given solid flow rate. The movement of solid material definitely ends with air speed v at the loosening point v_{AP}. The diagram indicates that a high carrier gas speed and a constant mass flow rate Q_S make it possible to change from dilute-phase conveying to gentler strand conveying by reducing the carrier gas speed. When the carrier gas speed is further reduced, a zone of pneumatic conveying is first traversed in which no stable conveying is possible. Yet, further reduction of carrier gas speed results in dense phase conveying, which protects the product. For granulated carbon blacks this conveying mode can be attained only if the conveyor line is equipped with an air bypass line. In this way the plug length is held constant.

Figure 10



Schematic representation of dilute phase conveying (above), strand conveying (middle), and dense phase conveying (below)

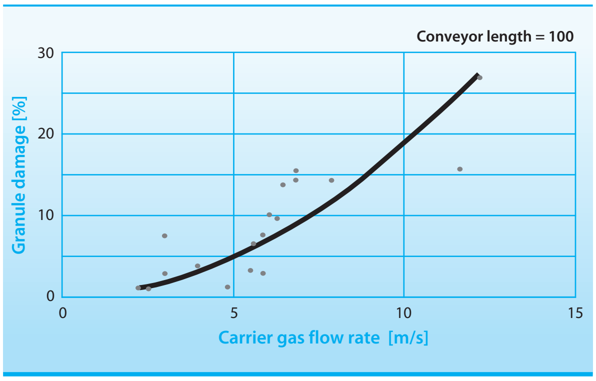
Figure 11



State diagram for pneumatic conveying (according to Geldart)

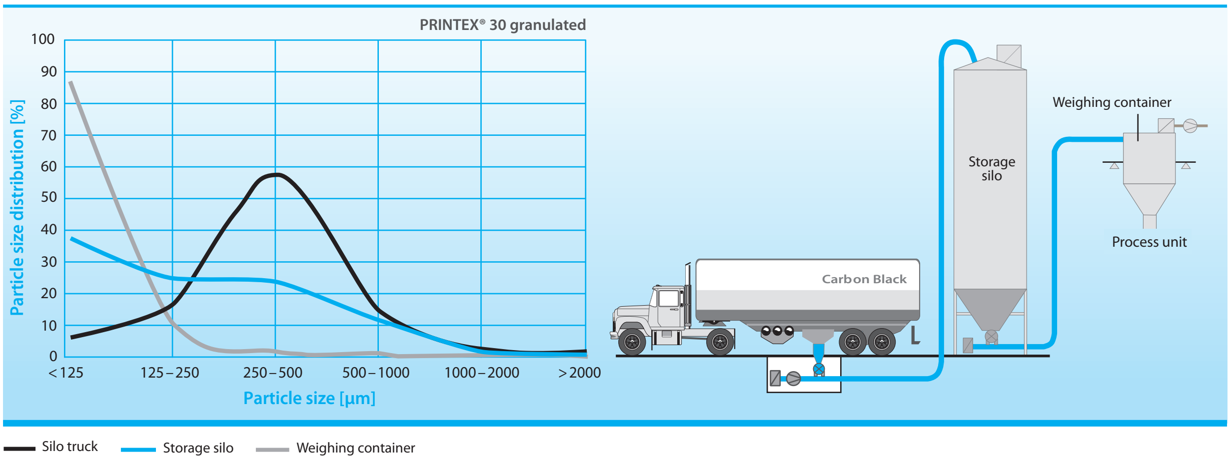
The choice of conveying method depends, among other factors, on the material to be conveyed. A high load is particularly desirable for granulated carbon blacks with a certain proportion of fines, because dense-phase conveying is associated with significantly lower particle abrasion than, for example, entrained flow conveying. The stress on the conveyed solid decreases with increasing load; in other words, the higher the load, the more gentle the conveying. This is reflected in the respective air flow rates (see **table 4**). The lower the flow rate of the carrier air, the lower the damage to the product. This is shown in **figure 12** for a conveyor length of about 100 m. The degree of abrasion increases approximately by a value between the square and the cube of the particle flow rate. **figure 13** shows the possible effect of the selected conveying method on product quality, using the example of granulated PRINTEX® R 30. It was delivered to the customer as per specification and with a narrow particle size distribution. A dilute phase conveying system (with a conveyor length of about 30 m) was used for unloading the silo truck. As a result, the proportion of fines (defined in the ASTM standard as particles < 0.125 mm), increased from 6 to 37 % after emptying. In addition to subsequent application problems, such as longer incorporation time in production, serious problems (adhesion to the walls, formation of bridges) arose when the product was removed from the storage silo. From the storage silo the carbon black was conveyed over a stretch of about 80 m (with dilute phase conveying) into a weighing container. As a result of the second dilute phase conveying, the proportion of fines increased further from 37 to 87 %, with a dramatic increase in the above mentioned problems.

Figure 12



Granule damage as a function of carrier gas flow rate

Figure 13

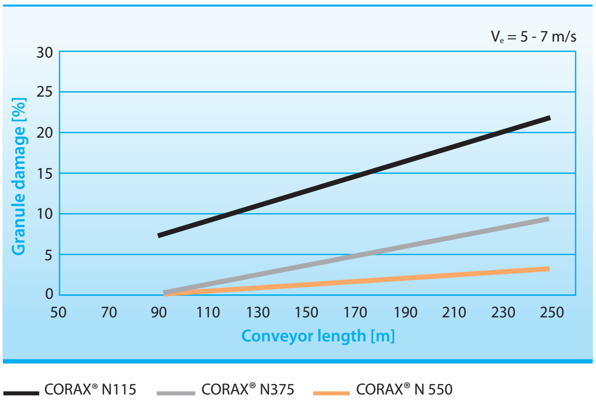


Effect of conveying method on product damage

In addition to choosing a suitable pneumatic conveying system, it needs to be ensured that the transport pathways from the storage silos to the production area are as short as possible. Like in the case of conveying speed, the shorter the conveying distance, the lower the proportion of fines generated.

As is clearly evident in **figure 14**, short conveying distances significantly reduce granule damage. This should be taken into consideration when planning new silo systems.

Figure 14



Granule damage as a function of conveyor length

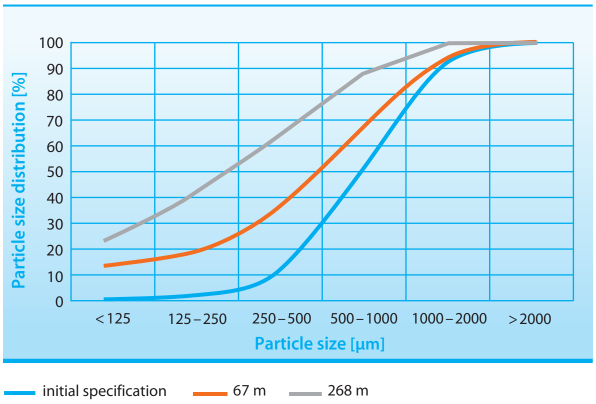
All Orion Engineered Carbons carbon blacks can be pneumatically conveyed with suitable systems.

4.1.1 Dilute phase conveying

This method uses high air speeds and is therefore particularly suitable for powder carbon blacks (see also load ratio in **table 4**). The high air flow rate fluidizes materials effectively and improves their flow properties. A distinction is made between pressure conveying and negative pressure conveying, with the latter also referred to as suction conveying. In pressure conveying, the conveyed material is forced through the line by overpressure. The blower is therefore located in front of the material feeder. This method theoretically permits conveying distances of up to about 250 m. In practice, however, such methods are only used for powder carbon blacks over much shorter distances (typically 15 – 30 m).

By contrast, the suction method uses a blower to generate negative pressure or a vacuum pump located at the end of the conveying path. This method, is only recommended for powder carbon blacks and for conveying distances of up to 30 m, for example for internal transport in step C of **table 3**. Investment costs for suction conveying are significantly lower than for pressure conveying. If dilute phase conveying is used with granulated carbon blacks, significant product damage needs to be expected. In turn, damaged granulated carbon black greatly increases the proportion of fines in the conveyed product. The longer the conveying distance in dilute phase conveying, the higher the proportion of fines generated, as is evident in **figure 15**.

Figure 15



Change in particle size distribution in the carbon black CORAX® N650 with the use of dilute phase conveying

Depending on the process steps involved in production (mixing, dispersion, etc.), parameters such as mixing time and dispersion time may be negatively impacted by the resulting high proportion of fines.

4.1.2 Strand conveying

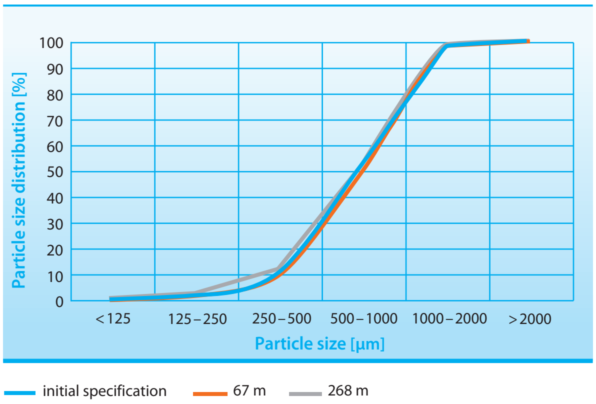
Strand conveying is another option for conveying substances that do not flow easily. As shown in **table 4**, it requires a higher degree of fluidization than the dense phase conveying described in section 4.1.3. The upper limit of the conveying distance for this method is about 300 m. For this distance, the hourly delivery rate may be in the range of a few metric tons.

4.1.3 Dense phase conveying

As mentioned above, dense phase conveying is particularly suitable for transporting granulated carbon blacks. This conveying method requires relatively high investment costs, but is the gentlest of all pneumatic conveying methods. Dense phase conveying is very reliable in operation. Even shutdowns of the unit in the loaded state, e. g. caused by, power outages or compressor failures, pose no problem because the conveying procedure restarts automatically.

Correctly designed systems that are appropriate for the conveyed product do not experience blocked transport lines. Dense phase conveying allows for conveying distances of up to a several hundred meters. However, conveyor performance deteriorates with increasing distance. Dense phase conveying of poorly flowing products can be facilitated by targeted feeding of secondary air at various line sections. Wear and tear on piping and at pipe bends are not significant in the transport of carbon black. For the above mentioned methods the degree of damage of the granulate during conveying is very small, as shown in **figure 16**.

Figure 16

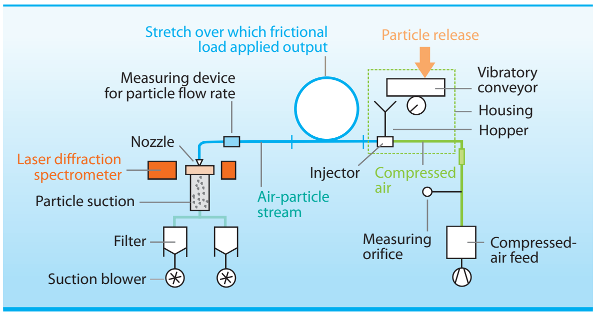


Change of particle size distribution in the carbon black CORAX® N650 with the use of dense phase conveying

4.1.4 Product damage

As mentioned in the previous section, product damage may occur to a greater or lesser degree in granulated carbon blacks, depending on the product properties and the type of pneumatic conveying. Brittleness is a basic quality criterion for estimating the transportability and flow properties in equipment and tanks as well as for abrasion resistance in process flows. Abrasion measurements (taken by applying stress in a sieve tower) as well as measurements of individual granule hardness (as per ASTM D 1508), that were prevalent in the past, are still used for characterizing the abrasion behavior of carbon blacks in response to stresses in pneumatic conveying systems. However, these parameters alone are not sufficiently informative. It is perfectly possible to produce carbon black granules with fairly low granule hardness that withstand the stresses of pneumatic conveying significantly better than the granule hardness would suggest. Presumably this is due to internal granule structure. The PCT (pneumatic conveying tester; see **figure 17**) was developed to reliably predict pneumatic conveying characteristics from product properties. This test apparatus subjects a particle sample to various kinds of frictional and/or impact stresses. These stresses are varied through the choice of experimental setups and based on the flow rate of the conveying air. Since the PCT provides data with sample quantities, it eliminates the need to conduct conveying trials on a pilot or production scale in the early stages of product development.

Figure 17

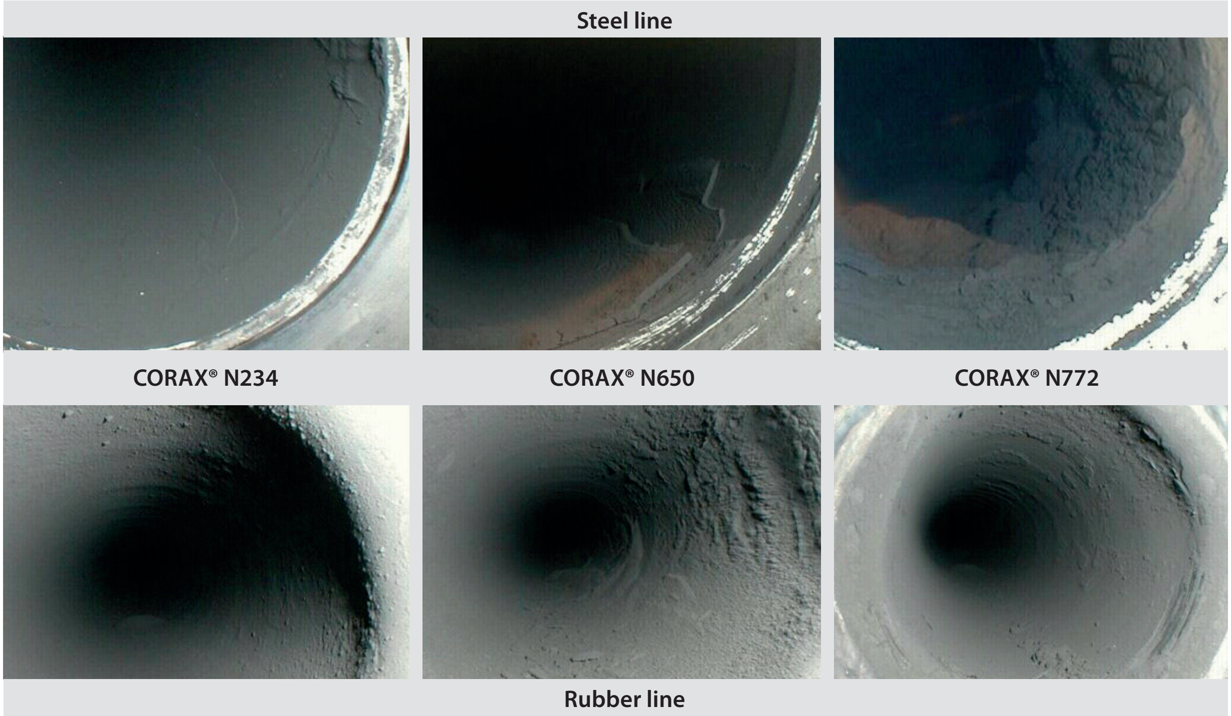


Schematic structure of PCT apparatus for application of frictional load

4.1.5 Adhesion behavior

The selection of conveying lines has to ensure that the material of the line is compatible with the material to be conveyed. For instance, carbon black grades that adhere to walls require the use of flexible plastic or rubber materials. Conveying lines with an elastic rubber inliner may be a suitable choice. The elastic inliner keeps adhesions short due to a "pumping" effect. The difference between the internal diameter of the steel pipe and the external diameter of the rubber inliner allows for movement. When the pressure in the pipeline increases, the inliner expands; for a pressure decrease, the reverse occurs. These pulsating movements dislodge adhesions and therefore serve as a form of self-cleaning. **figure 18** shows the adhesion behavior of various carbon black grades in a steel conveying line and in a line with a rubber inliner, using the carbon Black grades CORAX® N234, N650, and N772. The adhesion behavior of carbon black varies widely, depending on the surface area and structure. Carbon blacks of a low structure and a low specific surface area (such as CORAX® N772) have a strong caking tendency. By comparison, CORAX® N234 (with high structure and high specific surface area) shows negligible adhesion behavior. The higher the proportion of fines produced in transport, the greater the probability of caking. Due to the higher friction coefficient

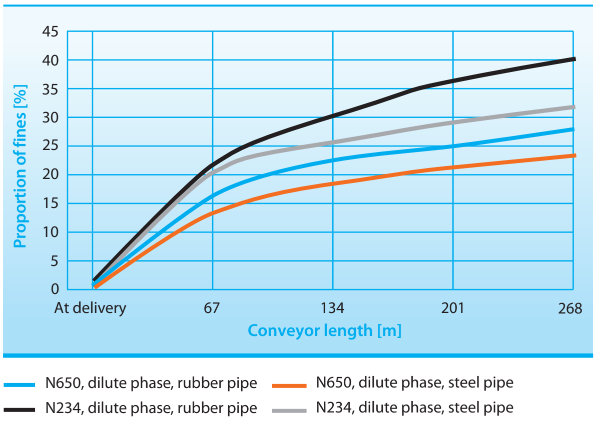
Figure 18



Adhesion behavior of various carbon black grades in steel and rubber lines after a conveyed distance of 600 m

between the carbon black and the rubber inliner, the proportion of fines for dilute phase conveying is slightly higher than for steel piping, as shown in **figure 19**.

Figure 19



Dependence of the fines proportion on the conveying length in steel and rubber pipes

To prevent the formation of deposits, metal pipes may require treatment with automatic low-frequency tapping devices under certain circumstances and at predetermined intervals.

High load ratios, low conveying speeds, abrasion-resistant and smooth inner piping surfaces, and few and wide pipe bends reduce the degree of granule damage and therefore the risk of caking. Dense phase systems with flexible conveying lines are recommended as universal conveying system for all carbon black grades. They are the only systems that reliably prevent adhesions and simultaneously minimize the increase in the proportion of fines during conveying.

4.3 Dust separators

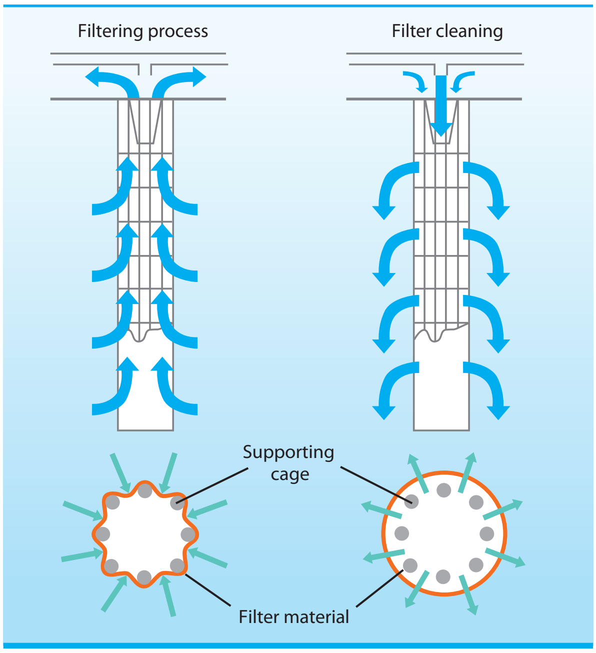
After pneumatic conveying, the transported carbon black must be separated from the conveying air, which is typically done by surface filters. These are filtering separators that periodically regenerate, or clean, the filter medium loaded with dust particles (see **figure 20**). Tubes or bags are typically used as filter media. Therefore, they are also referred to as tube or bag filters. In general tube filters are more efficient than bag filters. The cleaning mechanism consists of compressed air controlled by differential pressure or timing pulses. Most filter media consist of needle felts, which may be coated. Mechanical cleaning is not advised. The specific filter load of such filtering separators should not exceed 0.5 – 0.7 $m^3/(m^2 \cdot min)$ for powder carbon blacks and 0.7 – 1.0 $m^3/(m^2 \cdot min)$ for granulated carbon blacks.

Figure 20

Filtering separator/jet filter

4.4 Mechanical conveying

Mechanical conveying of bulk solids with bucket chain conveyors, screws, and tubular chain conveyors is historically the oldest technology for internal transport. Despite the advantages of pneumatic conveying, mechanical conveying is still the method of choice for certain applications because of special requirements. For instance, this is the case when granulates need to be handled with the least possible abrasion and granule damage.



Functioning principle of the filter (right)

4.4.1 Bucket chain conveyors

Continuous bucket chain conveyors, as shown in **figure 21**, are used whenever the conveying process has to be particularly gentle on the product. The carbon black can be transported horizontally, vertically, or over an inclined stretch. Mechanical conveying in bucket chain conveyors is energy efficient and very gentle on granules but requires high investments. In the case of strictly vertical transport lines, for example for silo charging, the cost of a bucket chain conveyor and a pneumatic dense phase conveying system will be approximately the same. In other cases the advantages of mechanical conveying, which is gentler on the product, clearly prevail.

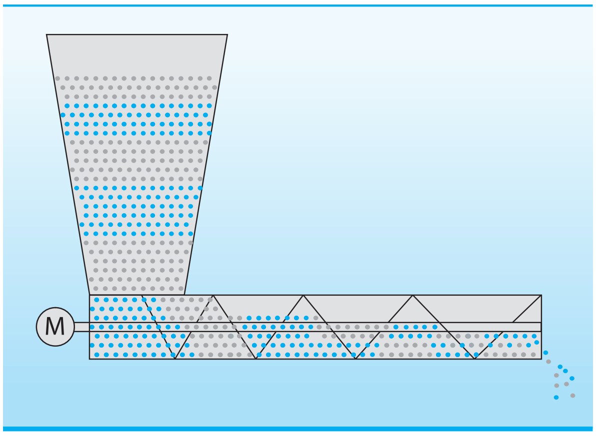
Figure 21

Continuous bucket chain conveyor for gentle transport of granulated carbon blacks (manufacturer: Nerak GmbH)

4.4.2 Screw conveyors

Screw conveyors may be used for short horizontal or slightly inclined conveying lines. This form of conveying results in minor loosening of powder carbon blacks, which improves incorporation into liquid media and makes a significant contribution to preventing unwanted air pockets. For granulated carbon blacks, the fill level of the screw conveyor should not exceed 50 %, which is easily achieved by using progressive screws (see **figure 22**). The use of screw conveyors is always associated with considerable granule damage – unless the bulk solid has the necessary space to flow. Incorrectly operated screw conveyors may lead to an increased fines proportion of up to 10 %.

Figure 22



Schematic illustration of a screw conveyer with progressive pitch

4.4.3 Tube chain conveyors

Tube chain conveyors may be used as alternative to bucket chain conveyors. Again, they provide the option to transport the product vertically, horizontally, or on an incline. Compared to bucket chain conveyors, they provide less gentle conveying of the bulk solid; their advantage lies in their lower investment costs. Due to possible granule damage, tube chain conveyors should be operated exclusively at slow conveying speeds (about 0.4 m/s) and mainly over short distances.

4.5 Buildup of electrostatic charge

Due to their chemical structure, all grades of carbon black are electrostatically dissipative. As a consequence, the safety data for carbon black (see safety data sheet) specify that the material has to be kept away from all sources of ignition. Electrostatically dissipative materials must be used for pneumatic conveying and storage of carbon black. Adequate grounding needs to be provided for all product-carrying parts of the entire conveying system.

5 Storage

Carbon blacks are supplied in a wide variety of packaging forms such as bags, semi-bulk packaging, and silo vehicles. Even though these packaging forms are closed containers (as for rigid semi-bulk packaging) or are protected by additional outer packaging such as polyethylene shrink or stretch film, carbon blacks should always be stored in dry, covered areas. The storage requirements described below should be reflected in the design of warehouses for bags or semi-bulk packaging and should always be followed – even for silo storage.

5.1 Storage conditions and lifespan

As stated above, carbon blacks need to be stored under dry conditions. Due to the highly dispersed character of this product, carbon blacks are always at risk of adsorbing vapors and/or gases, which can strongly affect its application properties. Therefore, carbon blacks should always be stored away from such sources of contamination. Storage temperatures may not exceed normal ambient temperatures (see also section 5.3) with 50 °C as a guide value for the upper limit. Although correctly stored carbon blacks have an indefinite lifespan, we recommend checking the application properties after a storage period of a maximum of 12 months since aggregation or adsorption processes may well affect application properties. This also applies to storage in silos or other closed containers.

5.2 Silo storage

Granulated carbon blacks delivered in silo vehicles require an adequate storage silo (see **figure 23**). If various carbon black grades are in use, several silos are needed. The information given below also applies to smaller containers such as intermediate or day silos. The design of the silos, and in particular silo geometry and discharge aids, must be tailored to the product properties of the carbon black.

Figure 23

Storage silos for carbon blacks

5.2.1 Silo geometry and volume

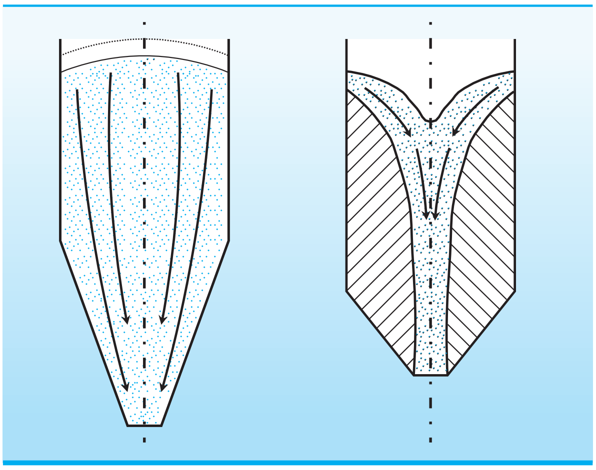
Slim, round silos with an axially symmetric cone are the preferred choice for silo storage of bulk solids, including carbon blacks. As a rule of thumb, the ratio of cylinder height H to silo diameter D should be no less than 3 ($H/D \geq 3$) because vertical pressures mostly depend on the diameter of the storage container. A favorable H/D ratio is advantageous for storing carbon blacks because excessively high pressures destroy the granules and can lead to compacting. The volume of storage silos is determined by delivery quantities and consumption. The volume of granulated carbon blacks delivered in a silo truck is about 60 to 90 m^3. Accordingly, the net volume of the silo is the volume of a delivery plus a residual volume to ensure uninterrupted production. The typical capacity of storage silos ranges from 100 to 120 m^3. Very large consumers, such as those in the tire industry, have significantly larger storage silos.

The angle of inclination of the hopper can be calculated, based on the properties of the bulk material, as shown in section 5.2.2. For cost efficiency, design and practical reasos, hopper inclinations of 20 to 30 ° to the vertical are used most frequently. Equipped with suitable discharge aids (such as those described in section 5.2.3) these cones allow smooth operation by using standard parts. The outlet diameter under the discharge aid should be no less than 200 mm to prevent the formation of stable bridges in this region. Most designs employ an aluminum alloy such as AlMg$_3$, or stainless steel 1.4301 or rather 1.4571. If regular steel is used, an internal coating should be applied for corrosion protection. However, the disadvantage of such coatings is the necessity to check their condition on a regular basis and that they may need to be reapplied. From the viewpoint of bulk solid mechanics, cold-rolled metal sheets are preferable to high-gloss coating surfaces (such as those obtained with two-component epoxy resins).

5.2.2 Determination of flow properties

The flow properties of pulverized substances and granulates vary widely. In many cases, the occurrence of flow problems is actually associated with the flow profile in a silo, which defines the movement of the bulk material in the silo. Mass flow and unwanted funnel flow are distinguished (see **figure 24**). Mass flow means the entire content of the silo moves as soon as bulk material is discharged. There are no dead zones and the bulk material flows along the hopper wall. In funnel flow, on the other hand, the bulk material flows out of a central zone with the formation of a discharge funnel, with dead zones forming at the periphery. In addition to the formation of bridges, funnel flow can cause undesired "piping", where bulk material flows only in a vertical tunnel. This makes residue-free emptying of the silo impossible.

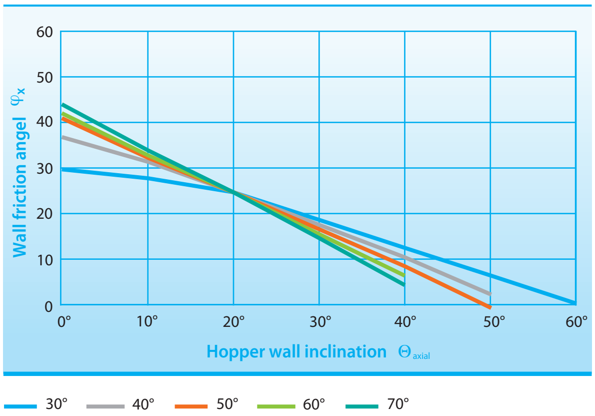
Figure 24



Schematics of mass and funnel flows. Details are given in DIN 1055, sheet 6.

Mass flow or funnel flow in silos is determined by the inclination Θ of the hopper wall measured from the vertical, the form of the hopper (conical or rectangular), the wall friction angle φ_x, between bulk material and wall material, and the effective friction angle φ_e. The boundaries between mass flow and funnel flow, which are obtained from the mathematical solution of the area of tension in the hopper, are shown in **figure 25** for a conical hopper (axially symmetric area of tension). DIN 50 281 provides a detailed description of the friction of bulk materials as the relative movement of bodies in contact.

Figure 25



Design diagram for mass flow, showing the wall friction angle φ_x as a function of hopper wall inclination. The parameter for the family of curves is the effective friction angle φ_e.

The friction angles φ_x and φ_e may be measured by means of shear devices or powder rheometers. The best known devices of this kind include the JENIKE translation shear device and the SCHULZE ring shear device. The values obtained from the measurements also allow for determining the minimum outlet diameter to avoid the formation of bridges. Whether mass flow or funnel flow occurs depends essentially on the wall friction angle φ_x. Therefore, the chosen wall material should have a low wall friction angle, at least in the hopper region. From a rheological viewpoint, uncoated metal surfaces provide more favorable flow conditions than coated surfaces.

Table 5

Product	φ_e	φ_i	φ_x (AlMg$_3$)	φ_x (1.4301)	φ_x (1.4301)	ς_x
PUREX® HS 25 (granulated)	40 – 41	39 – 40	18 – 20			346
PUREX® HS 45 Beads (granulated)	38 – 40	37 – 38	19 – 21			375
PRINTEX® alpha Beads (granulated)	41 – 43	37 – 42	19 – 21		34 – 36	398
PRINTEX® 25	40 – 47	28 – 37	33 – 37	34 – 37		165
PRINTEX® 25 Beads (granulated)	38 – 45	33 – 38	34 – 38	34 – 36		495
COLOUR BLACK FW 200	37 – 40	32 – 34	31 – 35			165

φ_x wall friction angle between bulk material and wall material

φ_e effective friction angle that indicates the internal friction of the bulk material for stationary flow

ς_b bulk density

Bulk technical data for some Orion Engineered Carbons products, as determined by the SCHULZE ring shear tester

Table 5 shows the values measured for the above mentioned friction angles for selected products. For some carbon blacks, the wall friction angle φ_x is only slightly lower than the effective friction angle φ_e. It is therefore practically impossible to construct silos with mass flow because the hopper wall inclination Θa_x would have to be between 0 and 15 °. Since this is technically not feasible, funnel flow silos with a hopper wall inclination angle Θa_x of 30 ° are usually built. To avoid the formation of vertical tunnels, discharge aids or devices with a large inlet cross-section are used. Vertical tunnels increase the risk of "flooding". If the outlet diameter necessary to prevent tunnel formation is calculated on the basis of filling pressures (for which a particular silo geometry must be specified), a 55 m^3 silo with diameters of 2.4 m and 3 m would result in the values shown in **table 6** (Incompressible). An alternative calculation for the critical outlet diameter to prevent vertical tunnel formation for compressible bulk materials relies on the area of tension at a given distance from the tip of the hopper of the silo discharge section. These values are listed in **table 6** (compressible). In practice, outlet diameters of silos range from 200 to 500 mm, depending on the mass flow required, and diameters of 2 m would be unusual. To avoid discharge problems, discharge aids must be used at the height of the critical outlet diameter calculated in **table 6**.

Table 6

Bulk material	Assumption		
	Compressible	Incompressible	
	D [mm]	$D_{2.4m}$ [mm]	$D_{3.0m}$ [mm]
COLOUR BLACK FW 200	200	1350 L 1150	
PRINTEX® 25	600	2400 L 2000	
PRINTEX® 25 Beads (granulated)	250	1850 L 1350	

D = minimum diameter required to avoid piping in a funnel-flow silo

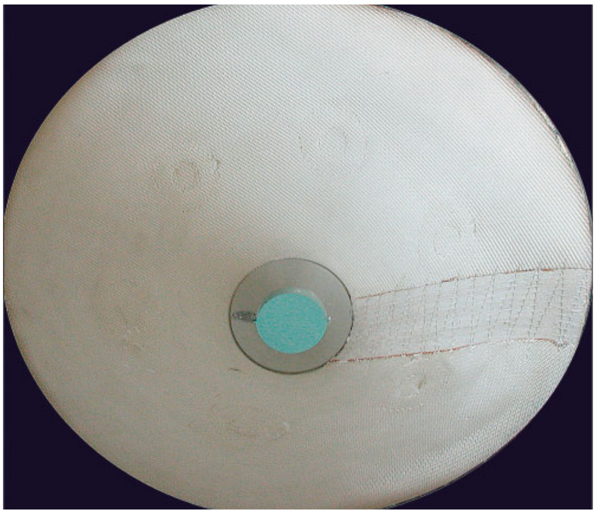
Critical silo outlet diameters (in mm) to avoid the formation of vertical tunnels, calculated for some carbon black pigments

5.2.3 Discharge aids

The purpose of discharge aids is to prevent the formation of stable bridges so the carbon black can be discharged from the silo easily at any time. They should be designed to allow residue-free emptying of silos. Discharge aids are generally attached to the cone at a diameter where no stable bridges may form. This diameter can be identified from the determination of flow properties as described in section 5.2.2. Storage silos for granulated carbon blacks commonly use two types of discharge aids. Vibrating plates are often employed on carbon black storage silos as discharge aids. They are domes or flat cones, which often have a counter-cone or a counter-dome installed above the outlet pipe to relieve the load. The entire unit is suspended at the cone of the silo so that it is free to vibrate. The remainder is connected to a flexible gasket/seal, which allows the vibration cone to agitate the bulk material and destroy any bridges in this region. The transmission of vibration to the body of the silo remains in an acceptably low range. Discharge aids may only be operated when the outlet pipe below is open and bulk material is being discharged.

The second type of discharge aid, which is gaining importance, works by fluidization. It can be designed in many ways, including as a double-walled cone that is flanged directly to the cone of the silo. Fluidization plates of this type (see **figure 26**) consist of an outer metal wall and an inner air-permeable wall made of fabric, sintered plastic, or sintered metal. Compressed air is blown into the inner space between the two walls and is introduced into the carbon black through the inner wall of porous material. This process, known as fluidization, significantly improves the flow properties of the carbon black by reducing internal frictional forces. As in the case of vibration plates, the diameter at which the fluidization plate is flanged to the silo cone must be larger than the longest possible stable bridge.

Figure 26



Interior view of a fluidization device: section of a TURBO-KONUS (manufacturer: AZO GmbH & Co.)

As an alternative to fluidization plates, individual fluidization zones or pipes/nozzles (see **figure 27**) may be used inside the silo cone. These fluidization devices must be positioned in such a way that the region of the cone to be fluidized can be uniformly accessed by the fluidizing gas. Again, the fluidizable cone region must have a diameter greater than the longest possible stable bridge.

Figure 27

Fluidization nozzle (manufacturer: Solimar Pneumatics)

5.2.4 Small silos for powder carbon blacks

As stated above, silo delivery of powder carbon blacks is not technically feasible. However, it may be necessary to use day-use or intermediate silos within the customer production facility. Such containers must be specifically adjusted to the bulk properties of the corresponding carbon blacks. The volume of intermediate silos or storage silos for powder carbon blacks should not exceed 5 m^3. It is best to determine the maximum feasible volume on the basis of the specific carbon black grade to avoid negative effects on the product, its handling, or application. Silo geometry should be guided by the same rules for the ratio of height to diameter as for storage silos ($H/D \geq 3$).

There are two design variants for the cone. The first is a cone that is as steeply inclined as possible (about 20 ° to the vertical), made of a flexible material such as rubber. Mechanical agitation then flex-levels the flexible cone and the carbon black can flow out of the small silo.
The alternative is a fluidization plate of the type described in section 5.2.3. For powder carbon blacks, the fluidization plate should cover the entire cone of the container. The suitability of these two options depends on the grade of carbon black.

5.2.5 Fill level measurement

Several systems are available for the measurement of the fill level in carbon black storage silos. The methods for measuring granulated and powder carbon blacks differ, and bulk and tapped densities must also be taken into consideration. The various delivery forms and carbon black grades may require different systems. The gravimetric method is the best approach to continuous fill level measurement. Although it is independent of delivery form and carbon black grade, it is the most cost-intensive variant. In this method, the silo is placed on load cells that continuously record the weight of the silo along with its contents. Up to four load cells are used, depending on the type and location of the silo setup. In most cases, static reasons make it difficult to retrofit existing silo systems with load cells, if it can be done at all. Although strain gauges can sometimes be used retroactively, they do not offer the same accuracy as load cells.

Capacitive measuring systems, that can continuously record the fill level, are less expensive and also suitable for retrofitting. Ultrasound measurement is another continuous method, which depends heavily on the carbon black grade and its bulk or tapped density. It should also be noted that ultrasound measurement may not work accurately when filling carbon blacks into containers because of the dust formation. Limit indicators are devices, that are triggered by vibrations or movements (see **figure 28**). Rotating paddle switches are frequently used for powder carbon blacks. The size of the paddle depends on the product, its bulk density, and the strength of fluidization. Vibrating detectors are a good option for granulated carbon blacks, with single-rod sensors being more suitable than tuning forks because of their lower tendency to cause carbon black caking.

Figure 28

Rotation paddle (manufacturer: UWT GmbH) and single-rod sensor (manufacturer: Endress & Hauser GmbH) as suitable limit level detectors

5.3 Safety aspects in storage

This section discusses the content of product safety data sheets. This does not absolve the carbon black user of the responsibility to read and follow the relevant safety data sheets. The storage of carbon black is subject to a number of safety instructions, that are detailed in the safety data sheets. During storage, carbon monoxide may be generated by air oxidation. Storage areas must therefore be appropriately ventilated to prevent carbon monoxide concentrations from reaching harmful levels. Carbon monoxide formation increases at higher temperatures, which is an important factor in case of fire. Moreover, carbon monoxide can form a hybrid mixture with air that is potentially explosive. If this is a possibility, as a result of inadequate ventilation, appropriate explosion protection measures need to be taken. Explosion protection has to be provided for all locations in the carbon black plant, where dust may be present in concentrations exceeding 50 g/m^3. Generally it is sufficient to keep carbon black clear from ignition sources.

Carbon blacks should never be stored above normal ambient temperatures. A few carbon black grades may ignite spontaneously in storage under extreme conditions. Storage silos should therefore be equipped with a well distributed supply of nitrogen (for example, via the fluidization plate discharge aid). For static reasons, fire in a storage silo cannot be fought with water. Injection of nitrogen is the simplest and most effective mean of fire fighting.

6 Metering

Metering carbon blacks plays an important role in internal handling. In all cases, where no entire bags with predefined amounts are used, weighing is necessary. Volumetric metering of bulk material is an alternative to gravimetric metering. However, it does not usually meet accuracy requirements and is therefore of lesser relevance. Most metering systems are gravimetric, with a distinction between continuous and discontinuous systems. The various metering options are decribed below.

6.1 Gravimetric systems

6.1.1 Discontinuous gravimetric systems

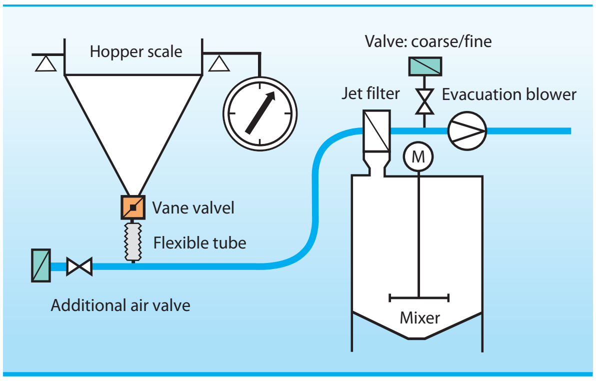
Two basic methods are available for discontinuous gravimetric metering of carbon black. In additive weighing, a weighing container is loaded until the required weight is reached, while subtractive or differential weighing involves removing a prescribed weight from a filled container. **figure 29** shows a conveyor scale installed over a mixer, as an example of additive weighing. The product is transported into the scale by a pneumatic suction conveying system. When the target weight is reached, the scale contents are emptied into the mixer.

Figure 29

Container scale for batchwise metering

Figure 30 illustrates the setup for differential weighing. The material is removed from the intermediate silo, which is designed as a scale and transported to a mixer. When the target weight is reached, the shutoff valve of the container closes and a false air valve is opened. The opening of this valve causes the material still in the conveying line to be transferred to the mixer. If only very small quantities are to be metered, a bag can be placed on a platform scale and the carbon black is suctioned directly out of the bag. This method corresponds to differential weighing.

Figure 30



Schematic of differential weighing

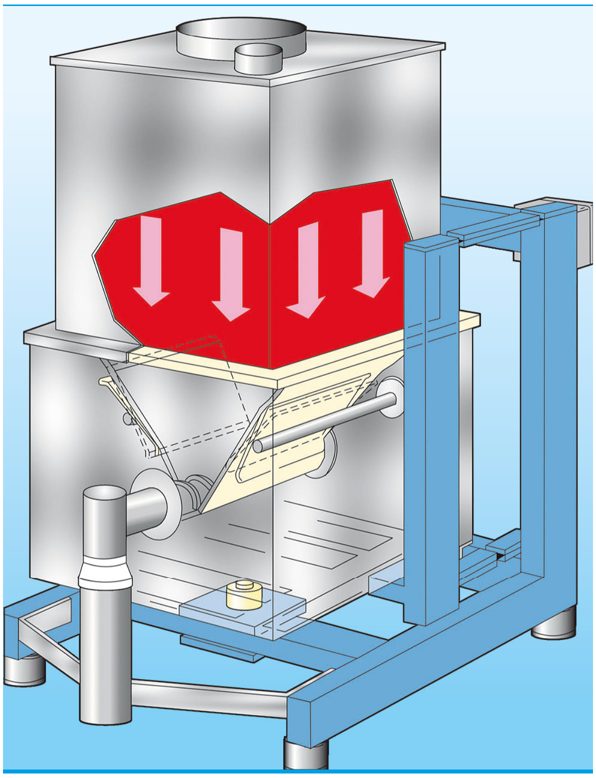
6.1.2 Continuous gravimetric systems

For continuous gravimetric metering of carbon black, differential metering scales have proven useful (**figure 31**). The differential metering scale consists of a screw conveyor, which is weighed along with the product in the storage container. While the screw conveyor moves the carbon black out of the storage container, the mass reduction per unit of time is measured to calculate the corresponding screw speed. During the rapid refilling of carbon black into the storage container, the differential metering scale briefly meters volumetrically. This process is highly accurate, as the required rotational speed is automatically determined from the screw speed previously used in the gravimetric metering. The settings of the differential metering scale must be adapted to the particular carbon black grade to achieve sufficient accuracy in continuous operation.

6.1.3 Volumetric metering

Volumetric metering is used only in cases, where metering accuracy requirements are low. In pneumatic conveying, the quantity may theoretically be set via conveying time or filllevel sensors in the receiving container. As a rule, this option is used only for filling containers from which gravimetric metering is then performed. The use of metering screws represents a slightly more precise method. The accuracy of such volumetric speed controlled metering screws is reliable in continuous operation only. The general accuracy of the process is about 5 %, depending on the uniformity of the bulk product density to be metered.

Figure 31



Schematic of a differential metering scale
(manufacturer: Brabender Technologie KG)

7 Product safety

7.1 Toxicology

Experience in humans

Over the decades of carbon black production and processing no harmful effects have been determined – given the carbon black is handled properly.

Acute toxicity

The acute oral toxicity LD_{50} rat is greater than 8,000 mg/kg. Values above 2,000 mg/kg are classified as non-toxic. Application of carbon black on the intact skin and in the eyes of rabbits does not cause irritation. Carbon black has not shown skin-sensitizing effects in animal studies.

Chronic toxicity

Animal study results published in the early 1990s showed that long-term inhalation or direct deposition of carbon black in the windpipe (intratracheal instillation) may cause chronic inflammation, pulmonary fibrosis, and formation of tumors under pulmonary overload conditions. These studies only documented positive results in rats; no tumors were recorded in mice and hamsters. The roles of the animal species, fine dust, and the mechanism of tumor formation have not been fully clarified. No carcinogenic effect was established in humans. Death-rate (mortality) studies on former workers in the carbon black industry in the U.K., Germany, and the U.S. showed no link between carbon black exposure and lung cancer. The International Agency for Research on Cancer (IARC) has confirmed this (citing "inadequate evidence") in its 1996 evaluation of carbon black. Due to the results of the rat trials, IARC classified carbon black in category 2B (possible human carcinogen). The IARC re-evaluated carbon black in early 2006 according to schedule, but made no change in classification.
On the basis of the IARC evaluation, carbon black has been included in the Danish national cancer list. Carbon black has been classified as a D2 A substance (poisonous and infectious material) under the Workplace Hazardous Materials Identification System (WHMIS) in the Canadian Environmental Protection Act (CEPA). In Germany the MAK (Maximale Arbeitsplatz Konzentration [Maximum concentration at workplace]) Commission classified carbon black in category 3B (possible carcinogenic action). In the U.S. National Toxicology Program (NTP) and in European (except Danish) and American chemicals legislation (OSHA) carbon black is not classified as mutagenic, teratogenic, or carcinogenic.

7.2 Ecotoxicology

Carbon black is not soluble in water; its bioavailability, and hence, its systemic toxicity to aquatic organisms is low.
In tests using carbon black filtrates with starting concentrations of 1,000 mg/l, no effects were observed on fish, daphnia, or algae. Carbon black is an inert inorganic material of structural formula C and is not degraded by microorganisms. In the classification of the KBwS (the German commission for the evaluation of water-polluting substances) carbon black is listed under identification number 1742 as a "non-water-polluting" material.

7.3 Safety properties

In practical conditions, carbon black is not potentially explosive. However, if large sources of ignition energy are present, for example in the form of a welding torch, carbon black/air mixtures may pose an explosion risk.
For this reason, all production areas under repair must be clear of carbon black. Carbon monoxide may be present in closed containers such as silos or in poorly ventilated storage areas. Such areas should be kept clear of ignition sources and self-contained respirators should be worn.
Carbon black should be stored under dry conditions. If the general dust limit exceeds a fine dust concentration of 3 mg/m^3 (Germany), or the total dust concentration exceeds 3.5 mg/m^3 (USA and most European countries) during the processing of carbon black, an air ventilation system or dust masks should be used. Spilled material should be collected mechanically to avoid dust formation, collected in suitable containers, and disposed in landfills or incinerated in appropriate facilities. Please refer to the corresponding safety data sheets for detailed measures associated with the safe handling of carbon black.

7.4 Special applications

Many carbon black grades comply with statutory provisions for additives used in food contact materials, toys, and drinking water applications.

For further information, please contact our product safety department:

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