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System selection criteria for successful vacuum transfer of fragile material

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When trying to vacuum convey friable materials, issues such as material degradation, abrasion, and segregation can create problems. This article discusses the importance of vacuum, material velocity, and phase flow when evaluating and choosing a vacuum conveyor system for fragile materials.

Successfully transferring fragile powders and bulk solids via vacuum without causing segregation or other material damage can be a challenge but one that's certainly possible when using the appropriate vacuum conveying system.

The fundamental components of all vacuum conveying systems are essentially similar. They consist of a vacuum generator, a pickup point, a conveying line, and an air–material separator commonly referred to as a filter-receiver. The difference in performance capabilities of the various vacuum conveying systems is governed by their achievable vacuum levels, their filtration systems, their ease of cleaning, and the "build quality" of the material being manufactured. All things being equal, however, the top consideration when choosing the system that's best for the application centers on achieving maximum material output with minimal material loss.

System selection criteria for achieving successful vacuum transfer of fragile material should address:

- The amount of vacuum generated and the velocity needed for the material being conveyed
- Potential material impact points in the conveying line
- The feeding system to be used to transfer material into the conveyor
- The elimination of pinch points throughout the conveying system

Consider the vacuum–velocity relationship

The first and most critical elements of these criteria are the velocity of the material being conveyed and the vacuum required to produce that rate of transfer. Plug dense-phase vacuum conveying typically has a velocity of 1,000 fpm or less but requires a vacuum pump capable of running at vacuum levels in the 20- to 22-inches-of-mercury range.

By definition, vacuum generation only has one atmosphere available for motive force, which equals approximately 30 inches of mercury or 14.7 psig at sea level. It stands to reason, therefore, that the greater the proportion of available vacuum that can be used, the more flexibility a system offers. Vacuum conveying systems using only a fraction of the available vacuum are limited in the type of material they can handle and the conveying velocity they can reach. This is why some companies restrict some vacuum generators to a limited pipeline size.

Vacuum-generating devices generally fall into the following categories:

- Regenerative or side-channel blowers — 7 to 9 inches of mercury vacuum (23 to 30 percent of full vacuum)
- Positive-displacement-type (roots) blowers — 15 inches of mercury vacuum (50 percent of full vacuum)
- Rotary claw-type blowers — 25 inches of mercury vacuum (80 percent of full vacuum)
- Multi-ejector, multistage venturi vacuum pumps — 27 inches of mercury vacuum (90 percent of full vacuum)

Of course, flow volume is also a critical factor to consider because the higher the solids-to-air ratio, the denser the conveying method becomes, while the lower the velocity level results in a higher vacuum level. When dealing with fragile material, one wants to operate the system at a lower velocity as doing so reduces degradation, segregation, and abrasion. This isn't possible with a regenerative or side-channel blower or with a majority of positive-displacement-type (roots) blowers.

Understanding why high velocity damages material is simple. Typically, the lean-phase conveying provided by the majority of vacuum conveying systems uses a velocity in the 4,000 to 6,000 fpm range (5,280 fpm is 60 miles per hour!). Couple that with the knowledge that powders don't flow around a bend, they bounce around it. To paraphrase Newton's first law, a body in motion stays in motion — and stays moving in the same direction unless acted upon by an external force. The powder particles continue in a straight line until they hit the wall of a bend and are subsequently harmed from that impact, potentially resulting in overall damage and reduced particle size.

Although one could look to minimize bends in the conveying lines, this is often impossible for many manufacturing operations. Reducing velocity, however, minimizes material impact and resultant damage. To avoid the damage-producing air velocity of systems using a fan or regenerative blower as the motion source, one can use a vacuum conveying system that uses a multi-ejector, multistage venturi pump. This type of system is able to reduce the airstream velocity to 750 to 1,500 fpm but obtain vacuum levels of 18 to 20 inches of mercury to convey a plug of material and, thereby, avoid the segregation and abrasion issues of other systems.

A case in point demonstrating the results of plug dense-phase conveying is when a test center conducted vacuum conveyor trials of freeze-dried coffee using a multi-ejector, multistage venturi pump as a motion source and maintained the coffee's bulk density with minimal damage (within a 0.02-grams-per-cubic-centimeter or 1.24-pounds-per-cubic-foot range) while conveying at rates of more than 5,000 pounds per hour. An increase in bulk density indicates smaller particles and, thus, levels of degradation. Results from vacuum transfer trials on other materials using a multi-ejector, multistage venturi pump, as shown in Table I and Figure 1, demonstrate similar results.

Choosing the optimal conveying phase

Determining the optimal conveying phase to maintain a fragile material's integrity will depend on a number of factors. They include the material's physical attributes, the material volume and conveying distance, the amount of vacuum needed to successfully transfer the material with minimal damage, and the related energy requirements. The quality of the filtration or separation system in maintaining optimal material transfer also is important.

Figure 1

Content particle size distribution across the batch (with standard deviation)

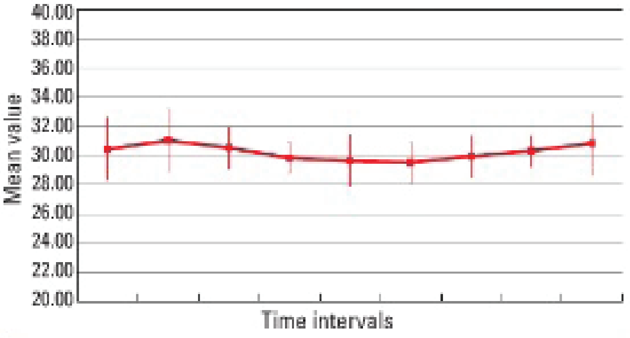


Table I

Results of dense-phase vacuum transfer trials of fragile materials

Sample point		Active Mg/Sachet				
		Paracetamol	Ascorbic acid	Citric acid	Total sodium	Total potassium
In Transfer (First pass through vacuum transfer unit)		1,030	30.1	983	322	289
		1,033	31.3	1,052	312	280
		1,028	30.6	1,189	291	267
		1,025	30.7	1,153	303	280
Top	Four passes through vacuum transfer unit	1,922	31.9	1,168	296	284
Middle		1,054	30.4	1,173	298	283
Bottom		1,043	31.1	1,197	296	274
Mean		1,034	30.9	1,131	303	280
%RSD		1.09	1.98	7.17	3.59	2.57

Individual results for the five actives are all within ±15 percent of their respective mean values, and all have acceptable percentage of relative standard deviation (%RSD). Even after four passes through the vacuum transfer unit, results for all actives remained unchanged. The results can, therefore, be considered as acceptable, and the formulation is considered suitable for use with dense-phase vacuum transfer.

Here's how lean-, semi-dense-, and plug dense-phase vacuum conveying can impact fragile materials:

Lean-phase conveying. Conveying by lean (dilute) phase is the least likely choice for fragile materials. In this phase, as shown in Figure 2, the resulting material load in the suction air is quite low, or "lean," and the speed of suction air is much higher than the saltation velocity of the individual material particles. The standard velocity is approximately 3,540 to 6,900 fpm, or 40 to 78 mph, resulting in increased particle damage and wear. Although conveying by lean phase can often achieve maximum flowrates — depending on the characteristic curve of the vacuum generator that's used — in the case of sensitive material, these high speeds can lead to increased particle damage.

Semi-dense-phase conveying. Depending on the material load needed, conveying by semi-dense phase (two-phase flow) can be the optimal choice for fragile material transfer. In this phase, as shown in Figure 3, the ratio of material velocity to air speed is less than 0 to 7. Semi-dense-phase conveying is gentle on material, and in terms of energy consumption can be the most favorable type of conveying by vacuum. Semi-dense phase occurs when the air speed is lowered to less than 4,000 fpm in a horizontal conveying pipe. In this situation, the conveyed material increasingly falls into the lower half of the pipe, resulting in "wave" movement of the material through the transport line. The actual wave formation greatly depends on the material. It can form individual plugs or settle so low in the line that the resulting reduction of material in the pipe cross-section increases the vacuum-generated air velocity and results in lean-phase conveying conditions prevailing above the dropped material.

Figure 2

Lean-phase conveying

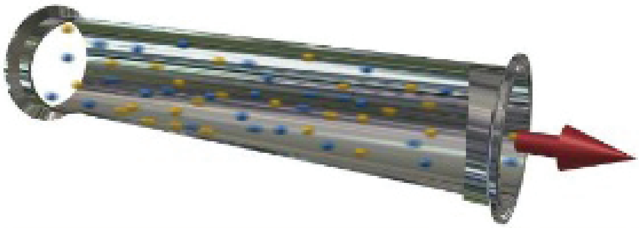


Figure 3

Semi-dense-phase conveying

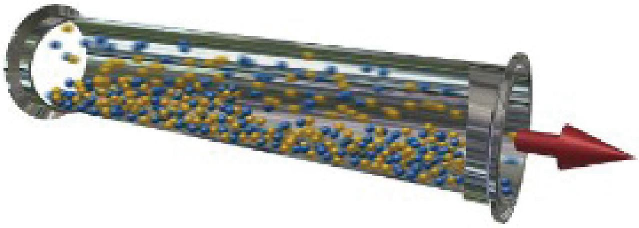
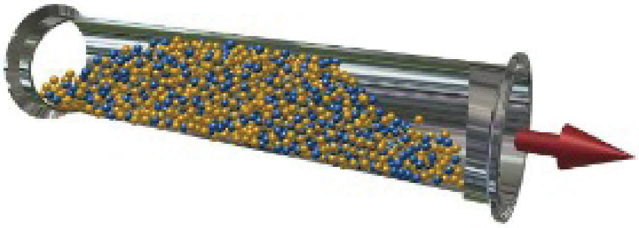


Figure 4

Plug dense-phase conveying



Plug dense-phase conveying. When the material load needed is increased beyond what's handled safely by semi-dense-phase conveying, plug dense-phase conveying is the best alternative. In plug dense-phase conveying, as shown in Figure 4, the increase in material load and further reduction in air velocity results in individual plugs forming in the conveyor line. As air moves through, the plugs fall away and continually rebuild themselves throughout the conveyor pipeline. Because of this gentle movement — even when conveying vertically — one can realize safe, reliable transportation of fragile materials when using a vacuum pump able to generate a high negative pressure with a sufficiently high airflow rate to prevent blocking of the suction pipe.

In plug dense-phase conveying, the air velocity is between 600 and 2,000 fpm, while the ratio of the material speed to air speed is less than 0 to 5. The material mass flowrate actually can be up to 100 times greater than the air mass flowrate. In terms of energy requirements, dense-phase conveying by plugs is comparable to lean-phase conveying because the required airflow rate is much lower while pressure difference increases in the same proportion.

As a general rule, the slower and more dense the conveying phase, the lower the conveyed velocity with less risk of material damage, system wear, and particle segregation. To achieve plug dense-phase flow, a higher level of vacuum is required, not achievable with common single-stage venturi systems or those set up to run side-by-side. Similarly, regenerative blowers and positive displacement electric pumps can't achieve sufficient vacuum levels on many materials.

Other considerations

Moving material through the vacuum conveyor without damage is certainly the major consideration in material transfer; however, the process of getting the material to and from the vacuum conveyor is also significant. These transfer points can be silo, bulk bag, 50-pound bag or sack, drum, granulator, dryer, or packaging line. A key factor in the system design is to use equipment that's free from and avoids the development of material pinch or impact points. This may include selective energy-absorbing features and designs.

Testing fragile material in a vacuum conveying system to ascertain the best conveying parameters is critical to successful results. Each material — and most applications — are unique to the company working with the fragile material. **PBE**

For further reading

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