Simultaneously Wetting and Dispersing
Powder induction into liquids

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A variety of methods are available to induct powdery materials into liquids. The main aim is to achieve an air-free dispersion of the solid material in the liquid. We distinguish between batch processes, in-line processes and processes where the product is produced in a batch system but is continuously pumped out of the processing vessel. Many users, not always familiar with powder treatment, normally opt for the continuous in-line system but they ignore the fact that powder is itself a dispersion of solid material in air. The air is an unwanted element in the final product. This article tries to determine the amount of air that is taken into the product when the powder is wetted and what effect that air has on the dispersion process.

Powder is a dispersion of solid material in air. The air fills the gaps between the solid particles but the amount of air in a powder is not constant. When the powder is supplied in bags on a pallet, the powder in the lower bags is compressed during transportation which means it contains less air than the bags on the top of the pile. The same applies to powder delivered in drums, BigBags and other large containers where the pressure gradient exists within the powder itself.

Amount of air
The amount of air in a powder may be calculated if the following parameters are known:
Bulk density (O_s) and the density (O). The bulk density (O_s) is determined by the mass and the volume while the density (O) is determined by the density of the solid material itself. The mass of the air may be ignored in this case.
The volume of the air (V_L) is calculated as follows:

$$V_L = m / O_s - m / O \qquad (1)$$

The amount of air thus depends on the mass (m) and is calculated in litres of air per kg or m^3/kg according to the following formula:

$$V_L / m = 1 / O_s - 1 / O \qquad (2)$$

Using this formula results in a wide range of figures. For a heavy powder, such as Titanium Dioxide (density approx. 4kg/l) each kilo of powder contains about 0.75l of air - this means about 75% of the powder volume is air. The amount of air is much higher with very light powders. For activated carbon the amount of air is approx. 2 l/kg and for fumed silica approx. 20 l/kg. These figures show that air is brought into the liquid regardless of the method used to put the powder into the liquid. When the powder is wetted in a liquid, that liquid takes the place of the air within the powder but, immediately after wetting, the air is still present in the liquid bulk.

Different wetting methods
If wetting is done in-line with no intermediate vessel to allow the air to bubble out, the air remains in the product. If, on the other hand, the product is circulated through the wetting machine and a vessel, the air can bubble out in the vessel. It is essential not to disperse the product immediately after wetting as this can disperse the air that is left in the product and so stabilise the air in the system. The air should be allowed to coalesce in the liquid, and then bubble out, allowing dispersion of the powder without any problems.

Induction without excess air
Air in powder is not all bad news. Indeed, there are many positive properties as well, not least of which is the fact that air is compressible. Under vacuum, therefore, the air expands and has a much larger volume. This increase in volume can be calculated from:

$$O_{L1} / O_{L2} = p_1 / p_2 \qquad (3)$$

The density of the air is directly proportional to the absolute air pressure. If the pressure is increased (i.e. if the powder is put under pressure) the air in the powder is compressed. A powder under a high confining pressure contains more air than a powder with less confining pressure and, under vacuum, the reverse is also true, as follows. When the powder is in the container from which it will be inducted (hopper, bag etc.) it is usually under atmospheric pressure but, as the powder travels from container to vacuum source, the pressure reduces until the vacuum source is reached. With an induction vacuum of 50%, the volume of the air is doubled whereas with a vacuum source of 90% the volume of air increases by ten times. The gap between the solid particles expands and the powder is loosened, thereby being fluidised without any extra air and making it much easier for the liquid to get between the solid particles to wet them properly.

Induction Vacuum
The induction path usually has a constant diameter and, because of the increase in volume caused by the increasing vacuum, the speed of the powder increases proportionally to the increasing volume. In the induction hose, for example, this means that the powder is accelerated more and more as it passes along the hose so that it reaches the vacuum source with a much higher speed than when it left the powder container. To use all these effects to their best advantage, the vacuum has to be produced exactly at the point of wetting.

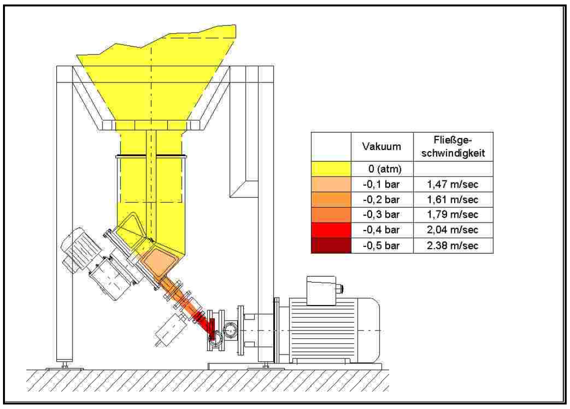


Figure 1 shows a wetting and dispersing machine that incorporates this principle. The machine is configured with a table that accepts the BigBag containing the powder. The vacuum is produced by a special rotor/stator system within the mixing chamber that causes a high flow of liquid. The vacuum produced can be as high as 50mbar abs (>95% vacuum) and, during induction, it adjusts itself automatically to the point when the powder starts to flow, thereafter remaining stable. The induction vacuum is determined by the flow characteristics of the powder and there is no requirement for any operator intervention. Light powders start to flow when the vacuum reaches 900mbar abs (10% vacuum) whereas heavy powders may require 50% vacuum (500mbar abs) or more.

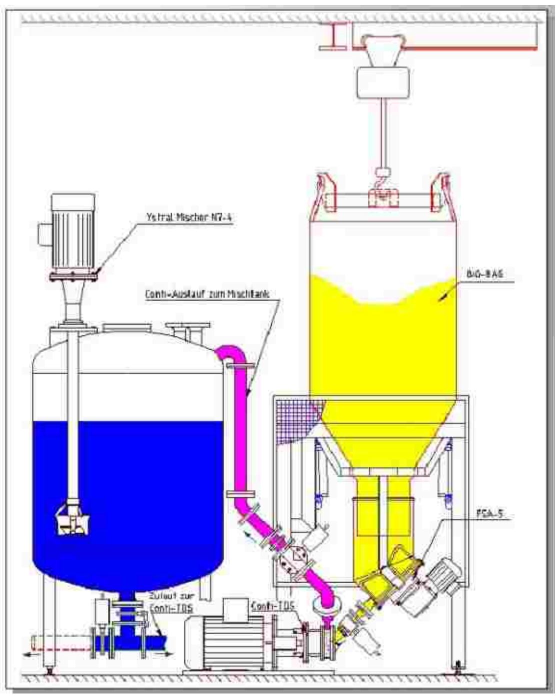
Dispersing during induction
The highly accelerated and fluidised powder must be fully wetted immediately it comes into contact with the liquid and the liquid must be ready to receive it. In the method described above, the powder and liquid are separate up to the point where the wetting is effected. At this point, the liquid is distributed into very fine, partial streams at precisely the same time as wetting occurs and this action is very intensive. There is a very high level of turbulence in the dispersing zone. Indeed, the shear gradient of the rotor/stator system is about 50 000 sec^{-1} which is between 1.000 and 10.000 times higher than that found with conventional stirrer, mixer or dissolver systems. To demonstrate this shear gradient, visualise the liquid being accelerated in a 500 µm gap from 25 m/sec (90 km/hr) to 0 m/sec and then back to 25 m/sec in the same size gap.

To summarise, the powder wetting is performed:

- under vacuum
- with large distances between individual particles
- with a highly accelerated powder stream
- directly into a dispersed liquid
- with maximum turbulence in the mixing zone
- with the maximum specific surface of the powder

The air contained within the powder is displaced resulting in complete wetting of the powder.

Dispersing after wetting
Just as the dispersion of the wetting liquid is essential during the wetting process it is absolutely essential that there is no dispersion of the product immediately after the wetting process. This is a major problem with systems which have a wetting stage followed immediately by a dispersing stage because the air which is still in the product is dispersed instead of the product and is thereby stabilised in the system. The low density of the air, and its compressibility, mean that the air is very easy to disperse and so it will be dispersed in preference to the powder particles, leaving, on the one hand, agglomerates of powder and, on the other hand, micronised air within the liquid. In almost any mixing process it is necessary to apply shear energy to achieve a better distribution of the solid particles (PSD), reduce the particle size or to accelerate the dissolving process. The air, therefore, must be allowed to bubble out from the product before the application of this shear energy so any wetting system followed immediately by a dispersing stage cannot be recommended.



Mixing Principles
Induction mixers are installed inside the vessel and produce the vacuum directly in the mixing head. This vacuum is used to induct the powder, through an induction hose, directly into the liquid in the head where it is wetted.

After this wetting process, the product leaves the mixing head and the air is able to bubble out of the product. With the Jetstream mixer, the flow is directed from the bottom of the vessel to the surface of the liquid and this flow pattern assists with the process of air release. Other mixers have the wetting point in the centre of the mixing head and the dispersing zone on the outer edge. The flow of liquid is directed from the top, through the mixing head towards the bottom of the vessel and so, in this stage, the dispersing zone has no effect on the product. The dispersing effect happens only after the air has bubbled out of the product. The best way to fulfil all the requirements of the inducting, wetting and dispersing processes for a powder in a liquid using vacuum principles is by using the Conti-TDS. This machine is normally used in a batch or semi-batch system by circulating liquid from a tank. The machine can also be used as an in-line machine or as a by-pass machine or by being installed in a filling line so that it adds powder while filling a tank.

Wetting methods

As noted above, the Conti can be installed as an in-line machine and this configuration is often chosen initially by users when the following processing stages are themselves continuous. However, this choice is often a limiting factor of the installation. For example, only one powder may be added in one pass through the machine and the dosing of the system has to be done by a gravimetric system as volumetric dosing is inappropriate. If a problem arises, such as blockage of the dosing system, foreign particles in the powder etc., this problem affects the whole production line, usually stopping it altogether. The air problem noted above must also be considered and, in all cases of this installation, we recommend a small buffer vessel to allow the air to be released.

The most common installation is as a batch or semi-batch system where liquid is charged to a vessel and then powder added and this method gives much more flexibility, especially when the product is then fed to a continuous production system. In 95% of all applications this method has all the advantages and none of the drawbacks. Dosing the individual components is easy - just place the vessel on load cells for the larger components of the process and use a simple dosing or pre-weigh system for any smaller components. Variations of powder quality, flow characteristics, lumps or agglomerates cannot influence final product quality because the wetting process is separate from the subsequent continuous process. It is, therefore, a very flexible system which can be universally adapted to existing processes.

Realisation

Design of a continuous process with a discontinuous wetting and dispersing stage can take one of four forms (Figure 3):

1.
Two vessels are operated alternately (flip/flop). One vessel is used to pump the dispersion to the downstream process while the other vessel is being cleaned and refilled. In this second vessel, the powder is inducted under ideal conditions and air has time to release from the product. In the case of 'difficult' powders, time can be allowed at this stage for additional shear energy to be applied or even for a different product to be made while the 'production' tank is emptying. With the Conti-TDS, all the above processes, including CIP cleaning between batches or products if required, can be performed with the same machine. This single machine is usually located between the two tanks to simplify piping design and minimise pipe-runs for easier cleaning.

2.
Operation with a production vessel and a buffer vessel is almost the same situation and the Conti can be used to transfer the product from production vessel to buffer vessel thereby saving on additional pumps (and additional cleaning!). To change the product mid-cycle is a little bit more difficult insofar as a second buffer vessel with cleaning facilities will be required (Figure 4).

3.
Applications which allow interruptions in the product transfer can operate with just a single vessel in place of the production and buffer vessels. When the filling level in the vessel reaches a 'low' sensor, transfer of the product is stopped and liquid and powder are added to the vessel until a 'high' sensor is triggered at which point transfer of product recommences. This set-up is mainly used when batches are produced in one shift and transferred in another shift but can also be used, for example, when the aim is to transfer solids to a filter bed such as in a water treatment plant.

4.
If no additional dispersing is required after wetting, the powder may be inducted in-line during the filling of a vessel. In this case the air will be released in the vessel. No sophisticated dosing systems are required since the powder container, bag or BigBag, can be placed on a differential weigh-station. The process appears to be an in-line one but is really a batch process, a typical example of which would be the addition of filter aid directly to the liquid while filling the vessel.